(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 January 2003 (23.01.2003)

PCT

(10) International Publication Number
WO 03/007068 A1

(51) International Patent Classification[7]: G02F 1/35, 2/00

(21) International Application Number: PCT/DK02/00480

(22) International Filing Date: 10 July 2002 (10.07.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/304,069 11 July 2001 (11.07.2001) US
01610077.8 11 July 2001 (11.07.2001) EP

(71) Applicant (*for all designated States except US*): DANMARKS TEKNISKE UNIVERSITET [DK/DK]; Bygning 101 A, DK-2800 Lyngby (DK).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): BISCHOFF, Svend [DK/DK]; Præstevej 12, DK-3480 Fredensborg (DK). MØRK, Jesper [DK/DK]; Folehavevej 53, DK-2970 Hørsholm (DK).

(74) Agent: PLOUGMANN & VINGTOFT A/S; Sundkrogsgade 9, P.O. Box 831, DK-2100 Copenhagen Ø (DK).

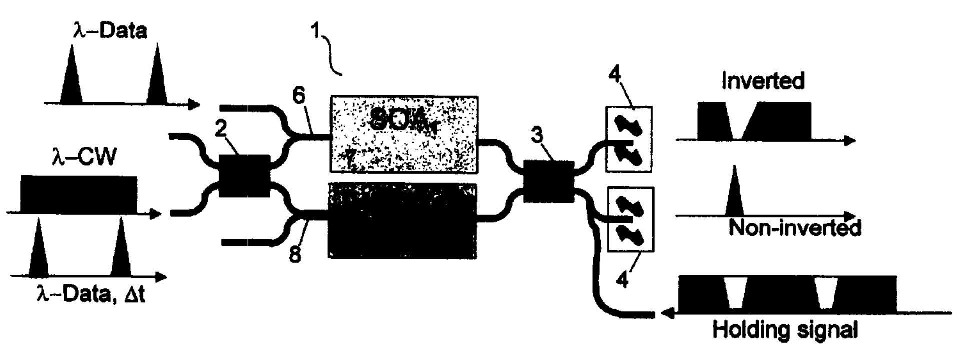
(81) Designated States (*national*): AE, AG, AL, AM, AT (utility model), AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ (utility model), CZ, DE (utility model), DE, DK (utility model), DK, DM, DZ, EC, EE (utility model), EE, ES, FI (utility model), FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK (utility model), SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Published:**
— *with international search report*

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

(54) Title: A METHOD AND AN APPARATUS FOR REDUCING AMPLITUDE VARIATIONS WHEN MODULATING OPTICAL SIGNALS IN SEMICONDUCTOR BASED COMPONENTS




(57) Abstract: The present invention relates to a method and an apparatus for improving processing of optical data signals such as gating, sampling, switching, regeneration, conversion, amplification, etc., in semiconductor based optical components. More specifically, the invention relates to reducing amplitude variations in modulations, such as amplification/absorption or phase shift, induced by intensity modulated data signals by overlapping an optical signal with the data signal in the semiconductor based optical component. Such amplitude variations arises because the amplitude of the induced modulations depends on the history of the preceding data signal due to the finite recovery time of the charge carrier density in the semiconductor based component. The invention reduces the modulation amplitude variations by applying a holding signal which also depends on the history of the preceding data signal in that it corresponds to an inverted and possibly low pass filtered version of the data signal.

WO 03/007068 A1

# A METHOD AND AN APPARATUS FOR REDUCING AMPLITUDE VARIATIONS WHEN MODULATING OPTICAL SIGNALS IN SEMICONDUCTOR BASED COMPONENTS

## FIELD OF THE INVENTION

The present invention relates to a method and an apparatus for improving processing of optical data signals, such as gating, sampling, switching, regeneration, conversion, amplification, etc., in semiconductor based optical components. More specifically, the invention relates to reducing amplitude variations in modulations induced by intensity modulated data signals, such as amplification, phase shift, or absorption induced by overlapping an optical signal with the data signal in the semiconductor based optical component.

## BACKGROUND OF THE INVENTION

Semiconductor non-linear elements such as e.g. SOAs (Semiconductor Optical Amplifiers) are used to modulate optical signals in a broad variety of optical components for amplification, switching, wavelength conversion, etc.

Zheng et al. (IEEE Photonics Tech. Lett., **12**, 2000,1091) describes a method for noise suppression from interferometric cross talk in SOAs in WDM (Wavelength-Division-Multiplexing) networks. This subject lies within a different field of technology than the present invention. The article describes that two multiplexed signals with orthogonal polarisation states, one signal being a data signal and the other being the complementary of the data signal with the same peak power, is used to feed the SOA with a constant input power. After amplification of the multiplexed signal, the orthogonal components of the signal are easily regenerated. Since the SOA experiences a constant input power, impairments like waveform distortion and extinction ratio degeneration are avoided.

In optical communication it is often of interest to obtain a high bit rate in the optical signals, the improvement of the present standards of 10 and 40 Gbit/s being restrained by the speed limitations imposed by the need for high speed electrical circuits. Performing signal processing in the optical domain will simplify the network management architecture and complexity. SOA have shown a large potential for performing all-optical signal processing like wavelength conversion, signal regeneration and de-multiplexing etc. by cross-gain modulation (XGM) or cross-phase modulation (XPM) in a Mach-Zehnder interferometer (MZI) or Michelson interferometer (MI) configuration.

Mach-Zender modulators utilise optically active materials to control a phase shift between two arms, an upper and a lower each comprising phase shifting elements (SOA), in an interferometer whereby the resulting signal may be modulated. The optical modulation of a

Mach-Zender modulator is done by injecting a modulated control signal into the upper arm thereby modulating the complex refractive index of the SOA. A second CW (Continuous Wave) signal is split so that a first part passes the upper SOA simultaneously with the control signal and is modulated by the phase shift induced by the control signal, while another part which passes the lower arm not is modulated. Upon recombining the two parts of the second signal, the combined signal will be amplitude modulated depending on whether the two parts are in or out of phase.

The performance of conventional semiconductor non-linear materials such as those used in SOAs has been limited significantly by the recovery time of the semiconductor optical gain medium. When applying optical data signals with high bit rates, the response of the medium will depend on the history of preceding pulses (bits) since the medium does not fully recover between to successive ones. The level to which the medium has recovered at a certain time thus depends on whether it has a history of ones or zeros. High electrical bias (high current or strong electric field) has been used with the semiconductor laser medium to maximise the recovery speed, but it has still not proved possible to obtain the recovery times necessary for operation at the highest data rates. Having a recovery time which is long compared to the period between bits results in amplitude variations in the modulations performed by the component, those modulations being amplification, phase shifting, absorbing, etc.

In MZIs, a modulated complex refractive index is induced in active semiconductor materials using intensity modulated control signals. A faster recovery of the charge carrier density and thereby the complex refractive index is obtained by injecting a third Continuous Wave (CW) holding beam, or increasing the power of the second CW signal, which results in an increased clamping of the SOA gain.

US 5,742,415 discloses a semiconductor based optical switching device with a reduced recovery time, where a holding signal is used to optically bias the gain medium in order to clamp the Fermi level of the conduction band in the semiconductor. The patent describes how the holding signal pumps the gain medium to repair the depletion made by a clock or data signal, whereby succeeding data pulses experience a non-depleted medium. The holding signal may be a continuous wave signal or may be pulsed with a pulse succeeding each pulse of a clock signal.

Nolting et al. (PDP 1, Integrated Photonics Research IPR 2001, June 11-13 2001) describes a switching device which can be used for fast pulse shaping and threshold switching at very high bit rates. The device uses a long SOA in which a data and a CW signal is inserted. Four wave mixing in the long SOA generates pulses complementary to the pulses

of the data signal, which suppresses carrier density fluctuations resulting from the pattern of the data pulses to overcome the conventional speed limit of the SOA.

## SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method and a device for reducing amplitude variations in modulations in optical signals when inducing modulations using optical data signals in semiconductor based optical components.

It is another object of the present invention to provide a method and a device for modulating electromagnetic radiation, which provides an enhanced extinction ratio and faster operation than obtained by XPM, XGM and four-wave mixing (FWM) in devices using semiconductor based optical components.

It is still another object of the present invention to provide a method and a device for reducing amplitude variations in signals generated in semiconductor based optical components, which method applies to all types of data signals, independent of the data content and data rate of the data signal.

It is still another object of the present invention to provide a method and a device for reducing amplitude variations in signals generated in semiconductor based optical components, which requires only a few extra components compared to existing modulators.

It is still another object of the present invention to provide a method and a device for reducing amplitude variations in signals generated in semiconductor based optical components, which can be combined with the different types of waveguides or interferometers.

The present inventions solves the problem of amplitude variations in modulations in optical signals resulting from inducing modulations using intensity modulated optical data signals in semiconductor based optical components.

According to a first aspect, the present invention provides a method for reducing amplitude variations in induced modulations in optical signals in semiconductor based optical components, the method comprising the steps of:

- providing a first semiconductor based optical component comprising an active region,
- directing an optical first signal to be modulated through the active region of the first semiconductor based optical component,

- inducing an amplitude or a phase modulation in the first signal by applying an intensity modulated optical data signal with amplitude A(t) to modify a complex refractive index of the active region, and
- reducing amplitude variations of the induced modulations in the first signal by applying an intensity modulated optical holding signal to prepare a charge carrier density of the active region of the first semiconductor based optical component, said holding signal having an amplitude B(t) corresponding to an inverted and possibly low-pass filtered version of A(t), B(t) being at least substantially described by

$$B(t) = B_0 - B_1 \int_{-\infty}^{t} e^{-(t-t')/\tau} A(t')dt', \qquad (1)$$

where $B_0$ and $B_1$ are constants determining the strength of the holding signal and $\tau$ is an integration time constant.

An intensity modulated optical data signal is a beam of electromagnetic radiation with varying intensity, wherein the variations in the intensity can be interpreted as information. Preferably, the data signal is a binary signal with zeros corresponding to low or no intensity and ones corresponding to pulses of higher intensity. It is preferable that the pulses are of substantially equal intensity, but intensity variations within some interval are generally acceptable.

The holding signal according to the present invention corresponds to an inverted and possibly low-pass filtered version of the data signal. In the present summary, description and claims, an inverted version of the data signal is an optical signal having an electromagnetic (EM) field amplitude which is, on a characteristic time-scale of the data signal, low when the amplitude of the data signal is high, and high when the amplitude of the data signal is low. Thus, the term inverse should not be restricted to an exact linear inverse proportionality between the data signal and the holding signal, as this will not be feasible with the present components. Rather the term inverse refers to a holding signal being modulated so that it compensates the variations of the data signal according to the gist of the present invention. Also, the overall EM field amplitude of the holding signal will typically be reduced in proportion to the overall amplitude of the data signal. In the case of a digital data signal, this means that the holding signal is "one" when the data signal is "zero" and vice versa. The peak (absolute) amplitudes, extinction ratio and modulation depth of the data signal and the holding signal may be the same but are typically not, the same goes for the wavelengths of the two signals. An exact inverted version of a signal thereby contains the same information as the original signal.

According to the present invention, the inverted version of the data signal may also be low pass filtered, which means that the high frequency components of the inverted data signal are removed. This corresponds to continuously going through the inverted data signal with an "averaging window" being a certain time slot (corresponding to the integration time constant $\tau$), and continuously taking the total power within that time slot as the low pass filtered signal. The low pass filtering "smoothes" the inverted data signal so as to remove rapid intensity modulations which is anyhow too fast for the material composition of the active region to follow. Thus, a low pass filtered version of a signal will generally not, depending on the used time slot, contain the same information as the original signal. Most devices for generating an inverted signal from a data signal will, if the data signal has a high bit rate (or rapidly varying amplitude), perform some low pass filtering du to the final response of the material compositions in the device.

The holding signal is preferably, but not necessarily, generated from the data signal. When the data signal carries information which is a non-periodic pattern (analogue or digital), the holding signal is preferably generated from the data signal in order for the holding signal to compensate for this pattern. In other cases, the data signal may be a substantially periodical signal such as a clock signal, in which case the holding signal may be generated independently of the data signal.

If the holding signal is to be generated from the data signal, the objective of the used technique will be to generate a signal corresponding to an inverted version of the data signal, which may however have different absolute amplitude, extinction ratio and modulation depth. Also, depending on the method used, the time slot (averaging window) within which the inverted signal follows the inverted version of the data signal, the possible low pass filtering, may be controllable or fixed to a finite value. Presently, the state of the art methods for generating an inverted version of a data signal are XGM or XPM of the data signal in an SOA. However, other improved methods for generating an inverted version of a data signal may emerge and is considered within the scope of the invention.

Hence, according to a second aspect, the present invention provides a method for reducing amplitude variations in induced modulations in optical signals in semiconductor based optical components, the method comprising the steps of:

- providing a first and a second semiconductor based optical component each comprising an active region,
- providing an intensity modulated optical data signal,
- splitting the data signal in a first part directed to the first semiconductor based optical component and in a second part directed to the second semiconductor based optical component,

- directing an optical first signal to be modulated through the active region of the first semiconductor based optical component,
- modulating a phase or an amplitude of the first signal by applying the first part of the data signal to modify a complex refractive index of the active region of the first semiconductor medium to generate a holding signal from the first signal, the holding signal corresponding to an inverted and possibly low-pass filtered version of the data signal,
- if a phase of the first signal is modulated, then directing the modulated first signal through an interferometer to generate the holding signal,
- directing an optical second signal to be modulated through the active region of the second semiconductor based optical component,
- inducing phase shifts in the second signal by applying the second part of the data signal to modify a gain or a refractive index of the active region of the second semiconductor based optical component, and
- reducing amplitude variations of the induced modulation in the second signal by applying the holding signal to prepare a carrier density of the active region of the second semiconductor based optical component.

In the present description, the term amplitude will be used in a number of different contexts. When referring to optical signals, the amplitude is the magnitude of the electric vector of the EM wave. When referring to modulations induced on the carrier electric field of an optical signal, such as an amplification/damping of the electric field amplitude or a shift in the phase, the amplitude is the absolute value attained by the modulation.

The modulation of the charge carrier density in the semiconductor material imposed by the intensity modulated optical data signal results in a modulation of the complex refractive index (refractive index contrast/gain coefficient) with a waveform which is closely related to the carrier density changes imposed by the data signal. The modulation of the refractive index contrast/gain then results in a modulation of a phase/amplitude of the first optical signal. The finite recovery time of the (exited) charge carriers in the active region sets a limit to the maximum rate/speed at which the waveform of the refractive index contrast/gain of the active region can follow the waveform of the data signal. Thus, at high modulation rates/speeds, the amplitude of modulations in the first optical signal varies depending on the history of the preceding waveform of the data signal. If the (exited) charge carriers have not fully recovered from a preceding high amplitude part of the data signal, the induced modulation will have a smaller amplitude than a modulation induced by the active region in which the (exited) charge carriers were fully recovered (no preceding high amplitude part of the data signal). As a result, the modulations induced by a part of the data signal preceded by a low amplitude part will have larger modulation amplitude

than modulations induced by the same amplitude part but preceded by a high amplitude part of the data signal. Modulation amplitude variations resulting from the semiconductor medium's dependence on the history of the preceding waveform of the data signal are a well known problem in the prior art, see e.g. IEEE Photonics Technology Letters vol. 9, no. 12, p. 1583-1585, "Technique for suppression of pattern dependence in a semiconductor-optical-amplifiers wavelength converter", D. Mahgerefteh, P. Cho, J. Goldhar and G. L. Burdge.

The invention solves this problem by applying the intensity modulated optical holding signal which also depends on the history of the preceding waveform of the data signal. By using a holding signal which corresponds to an inverted version of the data signal, the holding signal may counterbalance the effect of the preceding high or low amplitude part of the data signal on the induced modulation by reducing or equalising the total power fluctuations. This will reduce the modulation amplitude variations resulting from the preceding amplitude part of the data signal.

Preferably, the data signal is a binary optical signal comprising series of pulses separated by periods of substantially zero amplitude (depending on whether the signal is return to zero or not). In the following, the present invention will primarily be described with reference to cases where the data signal is a binary optical signal since this allows for a simple terminology when describing the waveform of the data signal, namely ones (pulses of high amplitude) and zeros (small or zero amplitude).

By using a holding signal which corresponds to an inverted version of the data signal, the holding signal introduces an increase in the optical intensity when the data signal is zero and vice versa. This corresponds to turning a CW holding signal on during a series of zeros and turning it off during a series of ones. The holding signal according to the present invention thereby introduces "a pulse" prior to pulses in the data signal, which is preceded by a zero. The first pulses in a series see the effect on the semiconductor medium from the holding signal, whereas the last pulses in a series see only the effect from the preceding pulses in the series. Thereby, all pulses in the data signal experiences approximately the same environment upon entry into the semiconductor medium, independently of the history of preceding pulses and their position in a series.

In an alternative point of view, the holding signal introduces an off set in the steady state zero-level carrier density (no optical data signal) in the active region compared to the case of no holding signal (i.e. the steady state zero-level carrier concentration would be higher when the data signal and holding signal amplitude is zero). The recovery time to the off set zero-level (lower concentration) is obviously faster than recovery to a higher lying zero-

level (larger concentration). From this point of view, the prior art CW holding signals introduce a constant off set in the zero-level concentration of charge carriers, however, this constant off set reduces the rate of stimulated carrier recombination induced by the data signal at high amplitudes, thereby reducing the amplitude variation moderately.

The response of an optical active semiconductor material to an EM field light is governed by the complex refractive index of the semiconductor material, generally denoted as n = Re(n) + i Im(n). The imaginary part Im(n) is related to the absorption or gain and determines the change of the amplitude of the EM field upon transmission in the semiconductor material, while the real part Re(n) of the refractive index determines the speed of light in the medium and thereby the phase of the transmitted signal. The complex refractive index depends on the excitation of the semiconductor medium and is a function with several variables like the signal wavelength, optical intensity, charge carrier density, material composition etc. The proper design of the static and dynamic material characteristics is therefore very complicated. However, upon comparison between models and experiments a reasonable control of the wanted material response is possible.

The modification of the complex refractive index, modulated by injecting the intensity modulated optical data signal into the semiconductor structure, is not restricted to the imaginary part of the refractive index. Also the real part of the refractive index will be modified. The change of the real part can be calculated from the changes in the imaginary part of the refractive index by the Kramers-Kronig transformation and is typically related to the gain change in the semiconductor structure by the line-width enhancement factor (alpha-parameter).

The induced modulation of the phase and gain depends on the intensity of the modulated data signal. Typical values for the power levels for the modulated data signal and CW signal in the literature are in IEEE Journal of Lightwave Technology vol. 14, no. 6, p. 942-954, 1996, "All-optical wavelength conversion by semiconductor optical amplifiers", T. Durhuus, B. Mikkelsen, C. Joergensen, S. L. Danielsen, K. E. Stubkjaer, specified to be 13 to -3 dBm for the CW signal and about -5 to 0 dBm for the data signal. However, these values depend on the SOA characteristics and the wavelength of the modulated data and CW signal. In other references quite different power levels are necessary for wavelength conversion due to different SOA characteristics. The paper IEEE Photonics Technology Letters vol. 9, no. 12, p. 1583-1585, "Technique for suppression of pattern dependence in a semiconductor-optical-amplifier wavelength converter", D. Mahgerefteh, P. Cho, J. Goldhar and G. L. Burdge, thus states power levels of 6 and 9 dBm for the CW signal and modulated data signal, respectively. The signal power levels are thus mainly determined

by the SOA characteristics and the operation wavelength and should be optimised for each device individually.

As mentioned in the above, the holding signal corresponds to an inverted and possibly low pass filtered version of the data signal and can generally be described according to Equation (1). In the simple example where the holding signal corresponds to an inverted version of the data signal, Equation (1) reduces to:

$$B(t) = B_0 - B_1 A(t). \tag{2}$$

From 2, it can be seen that the constant $B_0$ determines the peak amplitude of the holding signal whereas $B_1$ determines the "modulation depth" of the data signal A(t) in $B_0$, that is whether a pulse in the data signal corresponds to zero intensity in the holding signal.

In the case where the data signal is a digital optical signal, the generation of the holding signal comprises generating the holding signal so that it is inverse to the intensity modulations of the data signal on a time scale (or the integration time constant $\tau$ being) smaller than or equal to 4 times the bit period of the data signal.

Preferably, the holding signal follows the intensity modulations of the inverse data signal on a time scale (or the integration time constant $\tau$ being) smaller than or equal to 3 times the bit period of the data signal, such as smaller than or equal to 2 or 1 times the bit period of the data signal. Depending on the set-up and the specific components and materials, some low pass filtering is required so that the holding signal does not correspond to an exact inversion of the data signal, hence it may follow the intensity modulations of the data signal on a time scale within the interval of 1 - 3 times the bit period of the data signal, corresponding to the integration time constant $\tau$ being within the interval of 1 - 3 times the bit period of the data signal.

In another approach, if the data signal is a binary optical signal being based on a frequency component of X Hz, the method according to the first or second aspect of the present invention may be expressed as preparing the semiconductor medium, prior to the arrival of a first pulse corresponding to a bit of the data signal, by depleting the charge carrier density of the semiconductor medium, only if the data signal does not have a pulse preceding said first pulse within a time interval of $T = X^{-1}$ seconds. The depletion of the charge carrier density of the semiconductor is preferably performed using an optical holding signal.

The method according to the first and second aspect of the present invention applies to all cases where modulations are induced in a first signal by intensity modulations in a data

signal. The XGM and XPM methods mentioned earlier for generating the inverted version of the data signal may themselves be improved by using a holding signal according to the present invention.

In many applications, the semiconductor based optical component forms part of an interferometer, in which case the method preferably further comprises the steps of:

- splitting the first signal in a first and a second part before or after modulation,
- introducing a time delay $\Delta t$ and a phase shift $\Delta\phi$ in the first part of the first signal in relation to the second part of the first signal,
- coupling the first and the second part of the modulated first signal to form a resulting interference signal holding at least substantially the same information as the data signal.

Numerous interferometer types are applied in integrated optics today, such as Mach-Zehnder interferometer (MZI), Nonlinear optical loop mirror (NOLM), Michelson Interferometer (MI), Delayed Interference Semiconductor wavelength Converter (DISC), Ultrafast Nonlinear Interferometer (UNI), etc. The method according to the first and second aspect may be applied as long as modulations are induced by intensity modulations in a data signal in the semiconductor based optical component. Also, other interferometer types may emerge and the present invention is considered to be equally applicable in these.

The MZI represents an especially important and often used interferometer in the field of integrated optics. Hence, the first semiconductor based optical component may form part of an MZI which comprises a second semiconductor based optical component similar to the first semiconductor based optical component. In this case, the method preferably further comprises the steps of

- directing part of the first signal to be modulated through the active region of the second semiconductor based optical component, and
- coupling the part of the first signal emerging from the first semiconductor based optical component and the part of the first signal emerging from the second semiconductor based optical component to form a resulting interference signal holding at least substantially the same information as the data signal.

The Mach-Zehnder interferometer may advantageously be operated in differential scheme, in which case the method may further comprise the steps of

- directing part of the data signal through the active region of the second semiconductor based optical component, and

- applying the holding signal to the active region of the second semiconductor based optical component, and
- inducing a temporal delay between the signal parts coupled to form the interference signal.

In a third aspect, the present invention provides an optical device for inducing modulations in an optical first signal using an intensity modulated optical data signal, said optical device comprising

- means for generating an optical holding signal corresponding to an inverted and possibly low-pass filtered version of the data signal, said means having an input port for receiving at least part of the data signal and an output port for emitting the holding signal, and
- a first semiconductor based optical component for inducing modulations in the first signal corresponding to the intensity modulations of the data signal, the first component having an input port for receiving the first signal, an input port for receiving the data signal, an input port for receiving the holding signal, and an output port for emitting the modulated first signal.

Preferably, the optical device further comprises a splitter for splitting the data signal in a first and a second part, the first part being directed to the means for generating the holding signal and the second part being directed to the first semiconductor based optical component. Also, the means for generating the holding signal may use an optical second signal, preferably a CW signal, which is modulated by the first part of the data signal to form the holding signal. Hence, the means for generating the holding signal preferably further comprises an input port for receiving an optical second signal and one or more semiconductor based optical components connected to the input ports of the means for generating the holding signal for inducing cross gain modulations or cross phase modulations in the second signal to form the holding signal corresponding to the intensity modulations of the inverse data signal. If the one or more semiconductor based optical components are adapted to induce cross phase modulations in the second signal, the means may further comprise interferometer means for receiving the modulated second signal and form the holding signal.

As stated previously, the holding signal should correspond to an inverted and possibly low-pass filtered version of the data signal. This may be done in numerous different ways of which two, using the data signal for XGM or XPM, has been described in more detail above. Irrespective of how the holding signal is generated, the correlation between the waveform or bit pattern of the holding signal and the data signal is an utmost important feature. Thus, the means for generating the holding signal are preferably adapted to, given a data

signal having amplitude A(t), generate a holding signal having an amplitude B(t) being at least substantially described by

$$B(t) = B_0 - B_1 \int_{-\infty}^{t} e^{-(t-t')/\tau} A(t')dt', \qquad (1)$$

where $B_0$ and $B_1$ are constants and $\tau$ is an integration time constant. The values of $B_0$ and $B_1$ determines absolute amplitude, extinction ratio and modulation depth of the holding signal, while $\tau$ determines the time slot (averaging window) within which the inverted signal is inversely proportional to the data signal. The values of $B_0$ and $B_1$ and $\tau$ are mainly determined by the specific means for generating the holding signal, materials and the characteristics, e.g. wavelength and optical intensity, of a second signal from which the holding signal is generated.

Preferably, the means for generating the holding signal is an interferometer such as a Nonlinear optical loop mirror, Michelson Interferometer, Delayed Interference Semiconductor wavelength Converter, Ultrafast Nonlinear Interferometer, etc.

In a preferred embodiment, the means for generating the holding signal is a Mach-Zehnder interferometer comprising two semiconductor based optical components.

In many important applications, the present invention applies to a semiconductor based optical component which forms part of an interferometer. Hence, the optical device according to the third aspect may further comprise a first interferometer comprising the first semiconductor based optical component. The first interferometer may be an MZI, NOLM, MI, DISC, UNI, etc.

As the properties of the material composition of the semiconductor based optical components influence the correlation between the waveform or bit pattern of the holding signal and the data signal, this material composition should be selected appropriately. Preferably, the semiconductor based optical components comprises active regions comprising one or more materials compositions selected from the third (III) and fifth (V) group of the periodic system or from the second (II) and sixth (VI) group from the periodic system for e.g., GaAs, GaN, GaAlAs, InGaAs, InGaAsP, InAlGaAs, ZnSe, CdS, CdSe, etc.

One of the most promising applications of the present invention is within the field of integrated optics used in optical communication for generating, routing, controlling, detecting and working with optical data signals. Thus, in a preferred embodiment, the optical device is integrated in an integrated optical circuit. Also, the output port of the means for generating the holding signal and the input port for receiving the holding signal

of the first semiconductor based optical component are preferably connected by planar waveguides for guiding optical signals between them.

In the cases where only a single SOA is involved, it is generally important that the data signal and the holding signal do not add up to give a constant power since the information of the data signal will be lost and no modulation will be induced. However, in other cases where only one SOA is used, such as four-wave mixing and parametric oscillation, generation, or amplification, the information of the data signal may be preserved even if the data signal and the holding signal add up to give a constant power since the applied interactions depends on the relative polarisation states of the signals.

In a fourth aspect, the present invention provides a method for reducing amplitude variations in an optical signal generated by four wave mixing or parametric generation or amplification in semiconductor based optical components, the method comprising the steps of:

- providing a semiconductor based optical component comprising an active region,
- injecting an optical first signal being an intensity modulated data signal having an amplitude A(t) and a frequency $\omega_1$ into the active region,
- injecting an optical second signal having a frequency $\omega_2$ into the active region,
- generating an optical third signal by four wave mixing of the first and the second signals in the active region, said third signal having a frequency $\omega_3 = 2\omega_1 - \omega_2$ or $\omega_3 = 2\omega_2 - \omega_1$,
- reducing amplitude variations of the generated third signal by inducing an intensity modulated optical holding signal to prepare a charge carrier density of the active region of the semiconductor medium, said holding signal having an amplitude B(t) corresponding to an inverted and possibly low-pass filtered version of A(t), B(t) being at least substantially described by

$$B(t) = B_0 - B_1 \int_{-\infty}^{t} e^{-(t-t')/\tau} A(t')dt', \qquad (1)$$

where $B_0$ and $B_1$ are constants determining the strength of the holding signal and $\tau$ is an integration time constant.

If the holding signal is to be generated from the data signal, the objective of the used technique will be to generate a signal corresponding to an inverted version of the data signal, which may however have different absolute amplitude, extinction ratio and modulation depth. Also, depending on the method used, the time slot (averaging window) within which the inverted signal follows the inverse version of the data signal, the possible low pass filtering, may be controllable or fixed to a finite value. Presently, the state of the

art methods for generating an inverted version of a data signal are XGM or XPM of the data signal in an SOA. However, other improved methods for generating an inverted version of a data signal may emerge and is considered within the scope of the invention.

Thus, in a fifth aspect, the present invention provides a method for reducing amplitude variations in an optical signal generated by four wave mixing or parametric generation or amplification in semiconductor based optical components, the method comprising the steps of:

- providing a first and a second semiconductor based optical component each comprising an active region,
- providing an intensity modulated optical data signal having a frequency $\omega_1$,
- splitting the data signal in a first part directed to the first semiconductor based optical component and in a second part directed to the second semiconductor based optical component,
- directing an optical first signal to be modulated through the active region of the first semiconductor based optical component,
- modulating a phase or an amplitude of the first signal by applying the first part of the data signal to modify a complex refractive index of the active region of the first semiconductor medium to generate a holding signal from the first signal, the holding signal corresponding to an inverted and possibly low-pass filtered version of the data signal,
- if a phase of the first signal is modulated, then directing the modulated first signal through an interferometer to generate the holding signal,
- injecting an optical second signal having a frequency $\omega_2$ into the active region of the second semiconductor based optical component,
- generating an optical third signal by four wave mixing of the data signal and the second signal in the active region, said third signal having a frequency $\omega_3 = 2\omega_1 - \omega_2$ or $\omega_3 = 2\omega_2 - \omega_1$,
- reducing amplitude variations of the generated third signal by applying the holding signal to prepare a carrier density of the active region of the second semiconductor based optical component.

In the case where the data signal is a digital optical signal, the generation of the holding signal comprises generating the holding signal so that it is inverse to the intensity modulations of the data signal on a time scale (or the integration time constant $\tau$ being) smaller than or equal to 4 times the bit period of the data signal.

Preferably, the holding signal is inverse to the intensity modulations of the data signal on a time scale (or the integration time constant $\tau$ being) smaller than or equal to 3 times the bit period of the data signal, such as smaller than or equal to 2 or 1 times the bit period of the data signal.

In four wave mixing or parametric generation or amplification, the performance of the holding signal according to the present invention is generally optimised by making the holding signal as close to identical to the inverted data signal as possible. Thus, there is preferably no low pass filtering in the generation of the holding signal whereby $\tau \to 0$ so that B(t) becomes at least substantially described by:

$$B(t) = B_0 - B_1 A(t). \qquad (2)$$

In order to optimise the four wave mixing or parametric generation or amplification, the first and the second signals are preferably at least substantially parallel polarised. Also, in order to minimise the direct contribution of the holding signal on the four wave mixing or parametric generation or amplification, the first signal and the holding signal are preferably at least substantially perpendicularly polarised.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 shows the standard set-up for an MZI, where A and B show the co- and counter-propagation regime, respectively.

Figure 2A and B show the differential operation set-up for an MZI, where A and B show the co- and counter-propagation mode of operation, respectively.

Figure 3 shows the co-propagating differential set-up for an MZI, with a counter-propagating holding signal corresponding to an inverted version of the data signal.

Figure 4A and B show a DISC interferometer, where A and B show the non-inverted and inverted mode of operation, respectively.

Figure 5 and 6 show co-propagation mode DISCs with counter propagating holding signals. The figures illustrate the different effects of CW holding signals and holding signals corresponding to the present invention.

Figure 7A - C show eye-diagrams of the pulses of the converted signals resulting from the various holding signals.

Figure 8A-D and 9A and B show time sequences of a data pulse and examples of the corresponding holding signal.

Figure 10A shows a four-wave mixing set-up, 10B and C show the relative wavelengths of the injected and generated signals.

**DETAILED DESCRIPTION OF THE DRAWINGS**

Fig. 1A shows examples of wavelength conversion of a data signal in a Mach-Zehnder interferometer 1 in a co-propagation regime. The data signal is injected into one branch of the interferometer arms, while a CW signal onto which the information of the data signal is to be transferred, is injected into one of the input ports of a 2×2 coupler 2, which i.e. could be a multimode interference coupler. The CW signal is via the 2×2 coupler injected into both upper and lower arms 6 and 8 of the interferometer. Typically there is a phase difference of $\pi/2$ between the two signals at the output ports at the output of the 2×2 coupler 2. The gain of the SOAs in the two interferometer arms 6 and 8 is adjusted in such a way that the two fractions after passing the second 2×2 coupler 3 are either in phase or out of phase at one output port of the 2×2 coupler 3 when no data pulse is injected into the upper $SOA_1$ 7. The power of data pulses injected into $SOA_1$ is adjusted such that the data pulse results in a phase shift of approximately $\pi$ in this SOA. In this manner, the constructive (destructive) interference at the output ports of the 2×2 coupler 3 will be changed to destructive (constructive) when data pulses are injected into $SOA_1$. The electrical carrier injection will ensure that the phase change induced by the data pulse will be nullified with a characteristic time constant set by the carrier injection efficiency.

Figure 1B shows the MZI in the counter-propagation regime, working in the same way as in the co-propagation regime as shown in Figure 1A.

The wavelength of co-propagating signals should in general be different for both XGM and XPM, whereas the same wavelength for counter-propagating signals can be used. However, the same wavelength can be used in the co-propagating case, if the SOA waveguide is designed such that the different signals are propagating in different transverse modes. The splitting of the for e.g. data and CW signal after the SOAs is in this case not done by wavelength filters, but by multimode interferometers, which work as transverse mode filters.

In an MZI as shown in Fig.1A (or B) the data signal is injected into the upper SOA 7 resulting in a modulation of the complex refractive index. A second signal in form of a CW signal is injected in to the MZI through a 3-dB coupler or multimode interference coupler 2. A fraction of the CW signal is thus passing through the upper SOA 7 together with the

data signal, while the remaining fraction of the CW signal is passing through the lower SOA 9. The induced phase changes in the CW signal in the upper arm 6 depend on the waveform of the data signal.

In case no data signal is present and the two SOAs 7 and 9 are identical, the two fractions of the signals will be in phase after the SOAs and thus combine constructively in the upper arm of the output coupler 3 and destructively in the lower output port of the output coupler.

Modifying the phase change by $\pi$ of the upper SOA arm 6 by injecting a data pulse will result in destructive interference in the upper output port of the output coupler 3 and constructive interference in the lower output port.

The SOAs 7 and 9 are forward biased and after the data pulse has passed, the complex refractive index will recover towards its initial conditions due to the electrical injection of carriers. The destructive interference in the upper output port is thus slowly changed to constructive interference. Accordingly, the constructive interference in the lower output port is changing towards destructive interference after the data pulse has passed.

By modulating the refractive index, the gain coefficient will also be modulated whereby some gain changes will occur. The amplitude of the fraction of the CW signal passing the upper SOA 7 with the data signal will be modulated. This modulation of the CW signal amplitude results in a reduction of the extinction ratio (ER) when combing the two CW signals, since the amplitude of the CW signal passing the lower SOA 9 is constant.

The recombined CW signal, which is either the inverted or non-inverted version of the input data signal, will consist of pulses (in case of a data RZ signal), which are broader than the input data signal, since the transition from either constructive to destructive or vice versa is determined by the semiconductor material characteristics.

A method for avoiding this pulse broadening is the differential injection scheme shown in Figure 2A and B, showing the co- and counter-propagation regime, respectively. An attenuated copy of the data signal injected into the upper SOA 7 is now injected into the lower SOA 9 with a time delay $\Delta t$. The power of the data injected into the lower SOA 9 is adjusted such that the phase change of the CW in both interferometer arms 6 and 8 is approximately equal after passage of the data and delayed data pulse. In this manner the gain and phase changes of the two fractions of the CW signal will be identical for both SOAs 7 and 9 as the gain and refractive index are recovering due to carrier injection. The

period of constructive (destructive) interference at the output ports of the 2x2 coupler 3 will in this case be determined by the time-delay Δt between the two data signals.

In case of materials having a slow recovery of the charge carrier density, the gain and refractive index does not fully recover between two successive pulses, which will result in variations in the amplitude of the induced modulations when applying high bit rate data signals. In order to reduce these amplitude variations, the recovery time of the gain and refractive index is typically reduced by strongly forward biasing of the SOAs and injecting CW holding beams into the SOAs. The carrier injection efficiency can be strongly improved by applying a constant holding beam, which has been widely applied in gain clamped SOAs and in the MZI configuration described above.

The holding beam clamps the carrier density and thus the gain of the SOA to a level, which is significantly lower than the carrier density (gain) in the case of no holding beam. The stimulated recombination of carriers due to a data signal with high amplitude will reduce the carrier density and thus the gain of the SOA. The amplification of the CW holding beam is thus reduced when injecting a data pulse. The reduced amplification of the CW holding beam corresponds to a lower stimulated emission rate, which after passage of the data pulse leads to another mechanism of "carrier injection". The reduced amount of carriers removed by stimulated emission by the CW signal thus effectively gives a faster carrier density recovery rate. The explanation of the faster gain recovery is easily understood if one relates the given CW power inside the SOA to the corresponding virtual steady state carrier density.

The reduced CW holding beam power corresponds, if steady state was assumed, to a carrier density level which is higher than the initial steady state carrier density. The slope of the gain recovery is accordingly steeper compared to the case, where there is no CW holding beam. The CW holding beam thus results in an SOA state, which seems to be far from its virtual steady state carrier density level. The recovery rate of the SOA is thus faster in case of having a CW holding beam.

The invention results in an even faster gain/carrier density recovery time for the SOA by injecting a holding signal, which at least partially corresponds to the inverted data signal. The modulated holding signal results in a virtual steady state carrier density, which is even higher than in the case of a CW holding signal. This is because the holding signal power inside the SOA is not only reduced by the reduced gain when injecting a data pulse, but also reduced because the holding signal power itself is reduced when injecting

a data pulse. The carrier density recovery rate is thus further increased when using the data signal inverted holding signal, compared to the case of a CW holding signal.

Another way of viewing the influence of the CW and modulated holding signal is to focus on the total signal power injected into the semiconductor optical amplifier. In case of a CW holding beam the injected power variation is determined by the modulated data signal over a certain time, while a modulated holding signal will smooth out the total injected power, and as such result in less modulation of the carrier density (gain) of the SOAs.

Figure 3 shows a schematic of a MZI 1 in the differential injection scheme where an inverted signal is injected into the SOA acting as a holding signal. The inverted data signal may be generated by either XGM or XPM. The recovery time of the complex refractive index of SOAs is strongly influenced by such a holding signal when driven away from its steady state conditions by the applied data signal. The holding signal does not have to be a perfect inverted version of the data signal. Examples of possible modulated holding signal solutions and the corresponding data pulse sequence will be described in relation to Figures 8 to 10.

In order to avoid a change in the phase of the interferometer, the modulated holding signal may be injected into the two arms of the interferometer simultaneously. This becomes particularly important when the modulated holding signal is characterised by a relatively small integration time constant.

Figure 4 shows a DISC (delayed interference semiconductor wavelength converter). The working principle of the DISC interferometer is similar to the differential MZI configuration. The difference between the MZI and DISC interferometer is that the DISC interferometer contains only one SOA 11 where the interferometer itself is passive, consisting of a time-delay 12 and a constant phase shift 13. The data signal is injected together with a CW signal into SOA 10, where the phase and amplitude of the CW signal is modulated by the imposed change of the complex refractive index resulting from the co-propagating data signal.

After passage of the SOA 11, a 3 dB coupler or an MMI splits the CW signal into two arms of an interferometer 14. In the interferometer 14, one arm is delayed with respect to the other and a constant phase shift is introduced in one of the arms. After combining the CW signals from the interferometer arms, the interference between the delayed and phase shifted signals will regenerate the waveform of the data signal on the CW wavelength either in the non-inverted format (Figure 4A) or the inverted format (Figure 4B).

Figure 5 shows a simulation of a DISC interferometer 10 where either a low intensity CW (dashed line, prior art) or modulated (full curve, the present invention) holding signal is counter propagating through the SOA 11. The pulse width of the converted signal is set by the time-delay $\Delta t$. The parameter $\Delta\phi$ is a constant phase factor, which can be used for the optimisation of e.g. high extinction ratio. In case of the low intensity CW holding signal (dashed line), the resulting converted signal has large amplitude variations, in that the first pulses in a series experiences a much higher gain and refractive index contrast than succeeding pulses which experience a partly depleted complex refractive index.

As can be seen from the converted signal resulting from the holding signal according to the present invention (full curve) in Figure 5, the amplitude variations are strongly reduced by using the holding signal corresponding to a low pass filtered inverted data signal. Some difference in amplitude can still be seen between the first and the succeeding pulses in a series, and the remaining variations can be suppressed even further by optimisation of the method.

Figure 6 shows a simulation of a DISC interferometer 10 where either a high intensity CW (full line, prior art) or modulated (dashed curve, the present invention) holding signal is counter propagating through the SOA 11. This corresponds to the situation described in relation to Figure 5, except that the intensity of the CW holding signal (full line) is increased in order to improve the suppression of the amplitude variations in the converted signal. The holding signal according to the present invention and the resulting modulated signal (dashed curves) are identical to Figure 5.

It is clearly seen in Figure 6 that both the absolute amplitude and the amplitude variations of the converted signal are strongly reduced when the high intensity CW holding signal is applied. The relative amplitude variations, however, are only slightly reduced compared to Figure 5.

The reason for this is that the high intensity CW holding signal constantly depletes the charge carrier density in the active region. Therefore, the modulation (amplification and/or induced phase shift) will typically have much lower amplitude leading to lower absolute amplitude of the converted signal. Further, due to the constant depletion, the recovery to the depleted level will be faster simply because the difference is smaller. This accounts for the reduction in the amplitude variations.

The absolute amplitudes and the amplitude variations of converted signals resulting from the various holding signals described in relation to Figures 5 and 6 are summarised in Figure 7A-C. Figure 7A-C are eye diagrams showing the pulses of the converted signals

resulting from the various holding signals for constant $\Delta t$ values and for the optimum value of the constant phase shift $\Delta\phi$. Figure 7A shows the converted signal resulting from the holding signal according to the present invention (full curve in Figures 5 and 6); Figure 7B shows the converted signal resulting from the low intensity CW holding signal (dashed curve in Figure 5); Figure 7B shows the converted signal resulting from the high intensity CW holding signal (full curve in Figure 6).

In conclusion, as can be seen in Figures 7A-C, the holding signal according to the present invention results in a modest reduction in absolute amplitude and in a strong reduction in the amplitude variations. This can not be obtained using a CW holding signal as used in the prior art.

The inverted signal needs not be an exact version of the inverted data signal. The important issue is for the holding signal to deplete/off-set the complex refractive index so that pulses which have no immediately preceding pulse, will experience a complex refractive index as if there had been a preceding pulse. Hence if a period with no pulses occurs, which is long enough for the complex refractive index to recover significantly towards its original (undisturbed) value, the inverted signal should set in to deplete/off-set the complex refractive index. Thus, the inverted signal should typically follow the pulsed signal on a time scale comparable to the bit-period.

The inverted signal of the modulated data signal can e.g. be obtained by XGM or XPM. The requirements to the inverted signal are that a reasonable modulation of the inverted signal takes place during one to two bit periods. Examples of data pulse sequences and the corresponding holding signals (inverted data pulse sequences) are shown in Fig.8-10. It should be noted that the holding signals can generally not be used for retrieving the signal information.

The shape of the waveform of the holding signal according to the present invention, B(t), can be given by a simple expression emerging from the waveform of the data signal, A(t).

$$B(t) = B_{CW} e^{g_0 L} \left\{ 1 - \frac{g_0 L}{E_{sat}} \int_{-\infty}^{t} e^{-(t-t')/\tau_s} A(t') dt' \right\} \qquad (3)$$

This approximate relation can be derived from the rate equation describing the temporal variation of the charge carrier density in the waveguide. Here, $g_0$ is the small-signal gain, $E_{sat}$ is the saturation energy, $\tau$ characterises the (effective) recovery time constant of the medium and $B_{CW}$ is a parameter related to the input power level of a CW beam used to generate the holding signal. Equation 3 is equivalent to Equation (1), with

$$B_0 = B_{CW}\, e^{g_0 L} \tag{4}$$

and

$$B_1 = B_{CW}\, e^{g_0 L} \frac{g_0}{E_{sat}}. \tag{5}$$

Thus, overall B(t) corresponds to a low pass filtered inverted version of the data signal A(t). The parameter $\tau$ specifies the integration time slot or averaging window of the inverted signal with respect to the data pattern of the data pulses. The value of $\tau$ should be less than 2 to 4 times the bit period of the signal, which for a 40 Gbit/s signal corresponds to 50-100 ps, and 12-25 ps for a 160 Gbit/s data signal. The input power dynamical range of an MZI is typically low, thus that one cannot make a general statement about the input power requirements of the inverted data signal. The modulation depth of the inverted signal is typically of the order of 3-5 dB. A low ER of the modulated holding signal corresponds to a transition towards the CW holding beam case. The described method of improving the SOA dynamics by the invention will thus become less significant when decreasing the ER of the holding signal towards 0 dB.

The time constant $\tau$ specifies the characteristic memory time of the modulated holding signal with respect to the data signal. A very small $\tau$ value corresponds to an almost perfect inverted version of the data signal, while a very large $\tau$ value corresponds to very long memory time and thus a holding signal, which corresponds to the inverted version of the average data signal power.

The holding signal should to some degree give an estimate of the approximate average power contained within the data signal. However, the holding signal should also be modulated thus that the pattern effects of the data signal are visible. This sets an upper limit to the value of $\tau$, which is related to the bit period of the modulated data signal. Thus the value of $\tau$ should be lower than 2-4 times the bit period of the data signal.

The value of $\tau$ is in case of generating the modulated holding signal by XGM determined both by the material dynamics of the SOA as well as the length of the SOA. The material composition could e.g. be optimised for high-speed operation (20-40 GHz modulation bandwidth). The XGM efficiency is known to depend on the length of the SOA and the value of $\tau$ is thus reduced by increasing the length of the SOA. A description of the influence of the length of the SOA for both XGM and XPM for high-speed wavelength conversion can for e.g. be found in IEEE Journal of Lightwave Technology vol. 14, no. 6, p. 942-954, 1996, "All-optical wavelength conversion by semiconductor optical amplifiers", T. Durhuus, B. Mikkelsen, C. Joergensen, S. L. Danielsen, K. E. Stubkjaer. The length of the

SOA cannot be increased infinitely for improved XGM performance, since at a critical length the gain of the SOA will be saturated due to amplified spontaneous emission and the performance will not improve further. The quality of the XGM modulated signal with respect to memory effects and ER is thus controllable to some degree in case of XGM and XPM by varying the length of the SOA. The value of the input power level of the holding signal will depend on the excitation condition; for instance the wavelength of the holding signal. Typically, however, the intensity will lie within some range of the average power of the data signal.

The input dynamic range of a MZI is typically very narrow and as such the input dynamic range of the modulated holding signal for optimum operation will also be very narrow. The peak power values of the modulated holding signal should generally be several dBs lower than the peak power of the modulated data signal, since the modulated holding signal not is supposed to impose any significant phase changes on the CW signal onto which the modulated data signal is transferred. However, in the case of a MZI, as described in relation to Figure 3, the power of the holding signal may be comparable to the power of the data signal.

Figure 8A shows a 40 Gbit/s pulse sequence. Figure 8B, C and D show possible modulated holding signals corresponding to the data signal shown in A. The modulated holding signal may follow the pulse sequence quite well, which is observed by using a short $\tau$ time. In Fig. 8 D the integration time $\tau$ is much larger resulting in a less pronounced modulation of the modulated holding signal. The beam basically follows the average power over 2 to 3 bit periods. Figure 8C shows the case of an modulated holding signal, which has been generated numerically by taking a CW and subtracting the modulated data pulses after having broadened the data pulses to a width of several tens of pico-seconds. The shown modulated holding signal result in almost identical reduction in the patterning effects when doing XPM in an MZI. This demonstrates the large tolerance for the shape of the modulated holding signal.

Figure 9A shows a sequence of pulses of a 160 Gbit/s RZ signal, where the corresponding modulated data signal is shown in B ($\tau \sim 20$ ps). The modulated holding signal has a much longer memory time compared to the bit rate at 160 Gbit/s as shown for the case of the 40 Gbit/s examples shown in Figure 8. However, the modulated holding signal shown in Figure 9 is still sufficient to show a significant improved XPM performance in a MZI compared to the case with a CW holding beam.

The timing of when to inject the inverted signal compared to the data signal is quite relaxed. Depending on the shape of the inverted signal timing jitter of up to 12 ps for a 40 GHz signal will not result in any strong degradation.

Another application of the invention is the removal of pattern effects in Four-Wave Mixing (FWM) in semiconductor materials. The principle of FWM is to co-propagate an intensity modulated optical data signal together with a CW or intensity modulated optical signal through an SOA.

Fig. 10A shows a schematic of a FWM set-up, where a modulated data signal with frequency $\omega_1$ and a CW signal with frequency $\omega_2$ are injected into an SOA 15. Figure 10B shows the relative frequencies of the typically stronger data signal and the weaker CW signal to be switched. The best performance is obtained when the corresponding electromagnetic fields are parallel polarised. The data signal beats with the CW signal and gain and refractive index oscillations generated at the beat frequency scatter the first signal to the "mirror" frequency. As a result, a "conjugated" FWM signal is generated at the frequency $\omega_3 = 2\omega_1 - \omega_2$ or $\omega_3 = 2\omega_2 - \omega_1$ and intensity modulations corresponding to the data signal. Figure 10C shows the relative frequencies of the data signal, CW signal and the generated FWM signal. At the output, the data signal and the CW signal are removed using a wavelength filter 4.

The FWM signal increases with increasing amplification of the SOA. Amplification of a modulated data signal consisting of a PRBS signal will, when amplified in an SOA, result in a modulation of the SOA gain, which results in amplitude variations in the FWM signal.

In order to reduce amplitude variations in the generated FWM signal at $\omega_3$, a holding signal according to the present invention can be applied to the FWM set-up. The holding signal is also injected into the SOA 15 and can be co- or counter-propagating with respect to the data signal. The holding signal is intensity modulated corresponding to an inverted and possibly low-pass filtered version of the data signal. The injected power into the SOA will be constant and no amplitude variations in the FWM signal will be observed, if the holding signal corresponds to the inverted data signal. In order for the holding signal not to contribute in the four wave mixing of the data signal and the CW signal, the holding signal should exploit an orthogonal polarisation to the data signal and the CW signal. Thereby, the data signal and the CW signal only experience the effect of the holding signal on the charge carrier density in the SOA 15. If the Holding signal has a frequency different from $\omega_3$, it will be removed in the filter 4. Alternatively, it can be separated from the generated FWM signal by a polarisation filter.

In comparison to some of the other embodiments of the present invention, the FWM set-up is typically quite sensitive to the correspondence between the holding signal and the data signal. In the case of FWM, the best performance is expected when the holding signal is as close to an inverted data signal as possible and of comparable average intensity.

Only one FWM set-up is described. However, the present invention applies equally in a very large number of equivalent FWM set-ups as well as other higher order processes such as three-wave mixing, harmonic generation, optical parametric oscillation, generation, or amplification, etc.

The inventors have given a theoretical analysis of the principle of the present invention in S. Bischoff and J. Mørk, "Reduction of pattern effects in SOA-based all-optical switches by using cross-gain modulated holding signal", Techn. Digest, CLEO 2002, paper CWA53, p. 353, Long Beach, California, May 2002, which is hereby included by reference.

In the following, the most promising applications of the present invention are summarised:

1. Wavelength conversion. The invention may be used to reduce amplitude variations in case of wavelength conversion by XPM or XGM in devices incorporating semiconductor optical amplifiers at high bit rates.
2. Signal regeneration. The invention may be used to improve the signal regeneration capabilities of conventional interferometers incorporating SOA as the non-linear phase-shifting elements.
3. Functionalities such as switching, de-multiplexing, add-drop etc. may be significantly improved by the present invention.
4. All-optical logical functionalities. The invention may be improve the all-optical logical functionalities possible with SOAs, Mach-Zehnder Interferometers, Michelson Interferometers, Nonlinear Optical Loop Mirrors and Ultra-fast Non-linear Interferometers incorporating SOA as the non-linear phase-shifting elements. Logical functionalities like XOR have presently been demonstrated in a MZI,

In all the above examples, the invention will improve the performance of existing components.

**CLAIMS**

1. A method for reducing amplitude variations in induced modulations in optical signals in semiconductor based optical components, the method comprising the steps of:

- providing a first semiconductor based optical component comprising an active region,
- directing an optical first signal to be modulated through the active region of the first semiconductor based optical component,
- inducing an amplitude or a phase modulation in the first signal by applying an intensity modulated optical data signal with amplitude A(t) to modify a complex refractive index of the active region, and
- reducing amplitude variations of the induced modulations in the first signal by applying an intensity modulated optical holding signal to prepare a charge carrier density of the active region of the first semiconductor based optical component, said holding signal having an amplitude B(t) corresponding to an inverted and possibly low-pass filtered version of A(t), B(t) being at least substantially described by

$$B(t) = B_0 - B_1 \int_{-\infty}^{t} e^{-(t-t')/\tau} A(t')dt'$$

where $B_0$ and $B_1$ are constants determining the strength of the holding signal and $\tau$ is an integration time constant.

2. A method according to claim 1, wherein the data signal is a digital optical signal, wherein the integration time constant $\tau$ determines a time scale on which the holding signal follows the intensity modulations of an inverted version of the data signal, and wherein $\tau$ is less than or equal to 4 times the bit period of the data signal.

3. A method according to claim 2, wherein $\tau$ is less than or equal to 3 times the bit period of the data signal.

4. A method according to claim 2, wherein $\tau$ is less than or equal to 2 times the bit period of the data signal.

5. A method according to claim 2, wherein $\tau$ is at least substantially equal to the bit period of the data signal.

6. A method according to claim 2, wherein $\tau$ is within the interval of 1 - 3 times the bit period of the data signal.

7. A method according to any of the preceding claims, wherein the first semiconductor based optical component forms part of an interferometer and wherein the method further comprises the steps of:

- splitting the first signal in a first and a second part before or after modulation,
- introducing a time delay $\Delta t$ and/or a phase shift $\Delta\phi$ in the first part of the first signal in relation to the second part of the first signal,
- coupling the first and the second part of the modulated first signal to form a resulting interference signal holding at least substantially the same information as the data signal.

8. A method according to claim 7, wherein $B_0$ is smaller than the average peak amplitude of the data signal.

9. A method according to any of the preceding claims, wherein the first semiconductor based optical component forms part of a Mach-Zehnder interferometer further comprising a second semiconductor based optical component similar to the first semiconductor based optical component, and wherein the method further comprises the steps of

- directing part of the first signal to be modulated through the active region of the second semiconductor based optical component, and
- coupling the part of the first signal emerging from the first semiconductor based optical component and the part of the first signal emerging from the second semiconductor based optical component to form a resulting interference signal holding at least substantially the same information as the data signal.

10. A method according to claim 9, wherein the Mach-Zehnder interferometer is operated in differential scheme and wherein the method further comprises the steps of

- directing part of the data signal through the active region of the second semiconductor based optical component, and
- applying the holding signal to the active region of the second semiconductor based optical component, and
- inducing a temporal delay between the signal parts coupled to form the interference signal.

11. A method for reducing amplitude variations in induced modulations in optical signals in semiconductor based optical components, the method comprising the steps of:

- providing a first and a second semiconductor based optical component each comprising an active region,
- providing an intensity modulated optical data signal,

- splitting the data signal in a first part directed to the first semiconductor based optical component and in a second part directed to the second semiconductor based optical component,
- directing an optical first signal to be modulated through the active region of the first semiconductor based optical component,
- modulating a phase or an amplitude of the first signal by applying the first part of the data signal to modify a complex refractive index of the active region of the first semiconductor medium to generate a holding signal from the first signal, the holding signal corresponding to an inverted and possibly low-pass filtered version of the data signal,
- if a phase of the first signal is modulated, then directing the modulated first signal through an interferometer to generate the holding signal,
- directing an optical second signal to be modulated through the active region of the second semiconductor based optical component,
- inducing phase shifts in the second signal by applying the second part of the data signal to modify a gain or a refractive index of the active region of the second semiconductor based optical component, and
- reducing amplitude variations of the induced modulation in the second signal by applying the holding signal to prepare a carrier density of the active region of the second semiconductor based optical component.

12. A method according to claim 11, wherein the data signal is a digital optical signal, and wherein the step of modulating a phase or an amplitude of the first signal comprises the step of generating the holding signal so that the holding signal follows the intensity modulations of an inverted version of the data signal on a time scale smaller than or equal to 4 times the bit period of the data signal.

13. A method according to claim 12, wherein the holding signal follows the intensity modulations of an inverted version of the data signal on a time scale smaller than or equal to 3 times the bit period of the data signal.

14. A method according to claim 12, wherein the holding signal follows the intensity modulations of an inverted version of the data signal on a time scale smaller than or equal to 2 times the bit period of the data signal.

15. A method according to claim 12, wherein the holding signal follows the intensity modulations of an inverted version of the data signal on a time scale at least substantially equal to the bit period of the data signal.

16. A method according to claim 12, wherein the holding signal follows the intensity modulations of an inverted version of the data signal on a time scale within 1-3 times the bit period of the data signal.

17. A method according to any of claims 11 to 16, wherein the first semiconductor based optical component forms part of an interferometer and wherein the method further comprises the steps of:

- splitting the first signal in a first and a second part before or after modulation,
- introducing a time delay $\Delta t$ and/or a phase shift $\Delta\phi$ in the first part of the first signal in relation to the second part of the first signal,
- coupling the first and the second part of the modulated first signal to form a resulting interference signal holding at least substantially the same information as the data signal.

18. A method according to any of claims 11 to 17, wherein the first semiconductor based optical component forms part of a Mach-Zehnder interferometer further comprising a second semiconductor based optical component similar to the first semiconductor based optical component, and wherein the method further comprises the steps of

- directing part of the first signal to be modulated through the active region of the second semiconductor based optical component, and
- coupling the part of the first signal emerging from the first semiconductor based optical component and the part of the first signal emerging from the second semiconductor based optical component to form a resulting interference signal holding at least substantially the same information as the data signal.

19. A method according to claim 18, wherein Mach-Zehnder interferometer is operated in differential scheme and wherein the method further comprises the steps of

- directing part of the data signal through the active region of the second semiconductor based optical component, and
- applying the holding signal to the active region of the second semiconductor based optical component, and
- inducing a temporal delay between the signal parts coupled to form the interference signal.

20. An optical device for inducing modulations in an optical first signal using an intensity modulated optical data signal, said optical device comprising

- means for generating an optical holding signal corresponding to an inverted and possibly low-pass filtered version of the data signal, said means having an input port

for receiving at least part of the data signal and an output port for emitting the holding signal, and

- a first semiconductor based optical component for inducing modulations in the first signal corresponding to the intensity modulations of the data signal, the first component having an input port for receiving the first signal, an input port for receiving the data signal, an input port for receiving the holding signal, and an output port for emitting the modulated first signal.

21. An optical device according to claim 20, wherein the optical device further comprises a splitter for splitting the data signal in a first and a second part, the second part being directed to the first semiconductor based optical component, and wherein the means for generating the holding signal comprise an input port for receiving an optical second signal, one or more semiconductor based optical components connected to the input ports of the means for generating the holding signal by cross gain modulations or cross phase modulations in the second signal to form the holding signal corresponding to the intensity modulations of the data signal, and, if the one or more semiconductor based optical components are adapted to induce cross phase modulations in the second signal, then further comprising interferometer means for receiving the modulated second signal and form the holding signal.

22. An optical device according to claim 20 or 21, wherein the means for generating the holding signal is a Mach-Zehnder interferometer comprising two semiconductor based optical components.

23. An optical device according to claim 20 or 21, wherein the means for generating the holding signal is an interferometer selected from the list consisting of: Nonlinear optical loop mirror, Michelson Interferometer, Delayed Interference Semiconductor wavelength Converter, and Ultrafast Nonlinear Interferometer.

24. An optical device according to any of claims 20 to 23, wherein the means for generating the holding signal are adapted to, given a data signal having amplitude A(t), generate a holding signal having an amplitude B(t) being at least substantially described by

$$B(t) = B_0 - B_1 \int_{-\infty}^{t} e^{-(t-t')/\tau} A(t')dt'$$

where $B_0$ and $B_1$ are constants and $\tau$ is an integration time constant.

25. An optical device according to any of claims 20 to 24, further comprising a first interferometer comprising the first semiconductor based optical component.

26. An optical device according to claim 25, wherein the first interferometer is a Mach-Zehnder interferometer comprising two semiconductor based optical components both adapted to receive the first signal and the holding signal.

27. An optical device according to claim 25, wherein the first interferometer is an interferometer selected from the list consisting of: Nonlinear Optical Loop Mirror, Michelson Interferometer, Delayed Interference Semiconductor wavelength Converter, and Ultrafast Nonlinear Interferometer.

28. An optical device according to any of claims 20 to 27, wherein the optical device is integrated in an integrated optical circuit.

29. An optical device according to any of claims 20 to 28, wherein the output port of the means for generating the holding signal and the input port for receiving the holding signal of the first semiconductor based optical component are connected by planar waveguides for guiding optical signals between them.

30. An optical device according to any of claims 20 to 29, wherein the means for generating the holding signal and the first semiconductor based optical component comprises active regions comprising one or more materials selected from the third (III) and fifth (V) group of the periodic system or from the second (II) and sixth (VI) group from the periodic system for e.g., GaAs, GaN, GaAlAs, InGaAs, InGaAsP, InAlGaAs, ZnSe, CdS, CdSe, etc.

31. A method for reducing amplitude variations in an optical signal generated by four wave mixing in semiconductor based optical components, the method comprising the steps of:

- providing a semiconductor based optical component comprising an active region,
- injecting an optical first signal being an intensity modulated data signal having an amplitude A(t) and a frequency $\omega_1$ into the active region,
- injecting an optical second signal having a frequency $\omega_2$ into the active region,
- generating an optical third signal by four wave mixing of the first and the second signals in the active region, said third signal having a frequency $\omega_3 = 2\omega_1 - \omega_2$ or $\omega_3 = 2\omega_2 - \omega_1$,
- reducing amplitude variations of the generated third signal by inducing an intensity modulated optical holding signal to prepare a charge carrier density of the active region of the semiconductor medium, said holding signal having an amplitude B(t)

corresponding to an inverted and possibly low-pass filtered version of A(t), B(t) being at least substantially described by

$$B(t) = B_0 - B_1 \int_{-\infty}^{t} e^{-(t-t')/\tau} A(t')dt',$$

where $B_0$ and $B_1$ are constants determining the strength of the holding signal and $\tau$ is an integration time constant.

32. A method according to claim 31, wherein the first signal is a digital optical signal, wherein the integration time constant $\tau$ determines a time scale on which the holding signal follows the intensity modulations of an inverted version of the first signal, and wherein $\tau$ is less than or equal to 4 times the bit period of the first signal.

33. A method according to claim 32, wherein $\tau$ is less than or equal to 3 times the bit period of the first signal.

34. A method according to claim 32, wherein $\tau$ is less than or equal to 2 times the bit period of the first signal.

35. A method according to claim 32, wherein $\tau$ is less than or equal to the bit period of the first signal.

36. A method according to any of claims 31 to 35, wherein $\tau \to 0$ so that the amplitude B(t) of the holding signal corresponds to an inverted version of A(t), B(t) being at least substantially described by:

$$B(t) = B_0 - B_1 A(t).$$

37. A method according to any of claims 31 to 36, wherein the first and the second signals are at least substantially parallel polarised.

38. A method according to any of claims 31 to 37, wherein the first signal and the holding signal are at least substantially perpendicularly polarised.

39. A method for reducing amplitude variations in an optical signal generated by four wave mixing in semiconductor based optical components, the method comprising the steps of:

- providing a first and a second semiconductor based optical component each comprising an active region,

- providing an intensity modulated optical data signal having a frequency $\omega_1$,
- splitting the data signal in a first part directed to the first semiconductor based optical component and in a second part directed to the second semiconductor based optical component,
- directing an optical first signal to be modulated through the active region of the first semiconductor based optical component,
- modulating a phase or an amplitude of the first signal by applying the first part of the data signal to modify a complex refractive index of the active region of the first semiconductor medium to generate a holding signal from the first signal, the holding signal corresponding to an inverted and possibly low-pass filtered version of the data signal,
- if a phase of the first signal is modulated, then directing the modulated first signal through an interferometer to generate the holding signal,
- injecting an optical second signal having a frequency $\omega_2$ into the active region of the second semiconductor based optical component,
- generating an optical third signal by four wave mixing of the data signal and the second signal in the active region, said third signal having a frequency $\omega_3 = 2\omega_1 - \omega_2$ or $\omega_3 = 2\omega_2 - \omega_1$,
- reducing amplitude variations of the generated third signal by applying the holding signal to prepare a carrier density of the active region of the second semiconductor based optical component.

40. A method according to claim 39, wherein the data signal is a digital optical signal, and wherein the step of modulating a phase or an amplitude of the first signal comprises the step of generating the holding signal so that the holding signal follows the intensity modulations of an inverted version of the data signal on a time scale smaller than or equal to 4 times the bit period of the data signal.

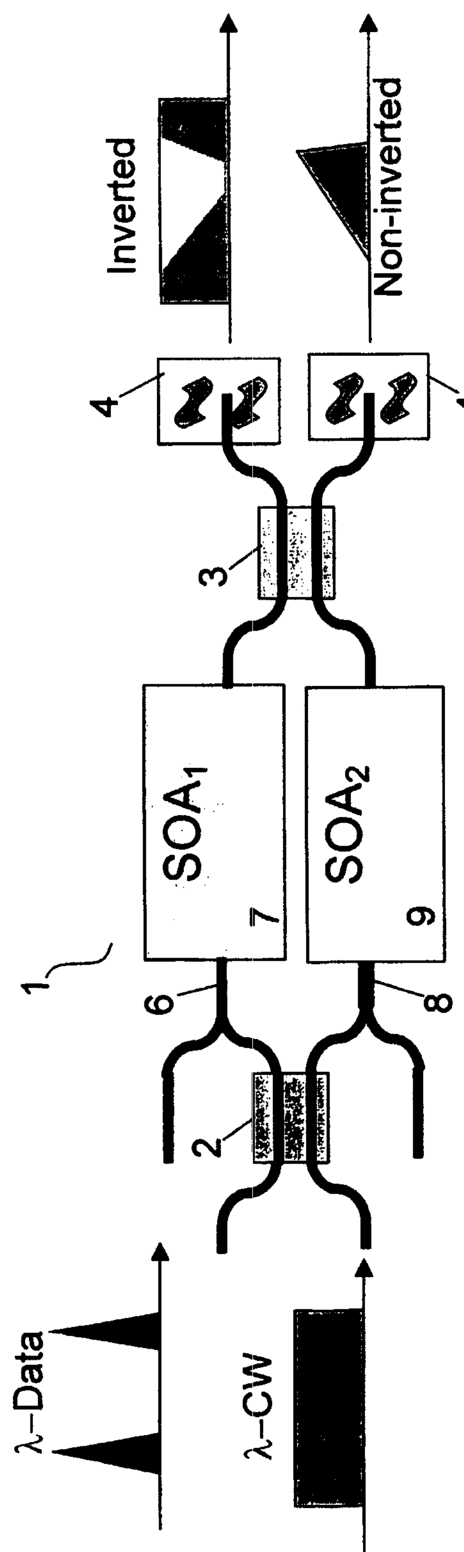
41. A method according to claim 40, wherein the holding signal follows the intensity modulations of an inverted version of the data signal on a time scale smaller than or equal to 3 times the bit period of the data signal.

42. A method according to claim 40, wherein the holding signal follows the intensity modulations of an inverted version of the data signal on a time scale smaller than or equal to 2 times the bit period of the data signal.

43. A method according to claim 40, wherein the holding signal follows the intensity modulations of an inverted version of the data signal on a time scale at least substantially equal to the bit period of the data signal.

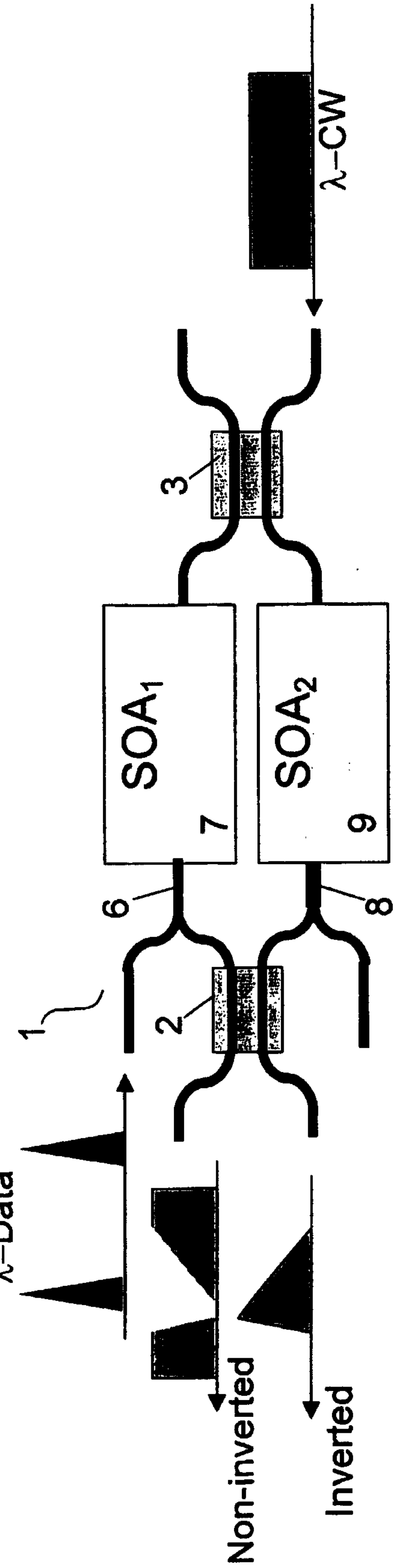
44. A method according to any of claims 39 to 43, wherein the first and the second signals are at least substantially parallel polarised.

45. A method according to any of claims 39 or 44, wherein the first signal and the holding signal are at least substantially perpendicularly polarised.



λ–Data
λ–CW
1
2
3
4
4
6
8
SOA1
SOA2
7
9
Inverted
Non-inverted


Fig. 1A



λ–Data
λ–CW
1
2
3
6
8
SOA1
SOA2
7
9
Non-inverted
Inverted


Fig. 1B

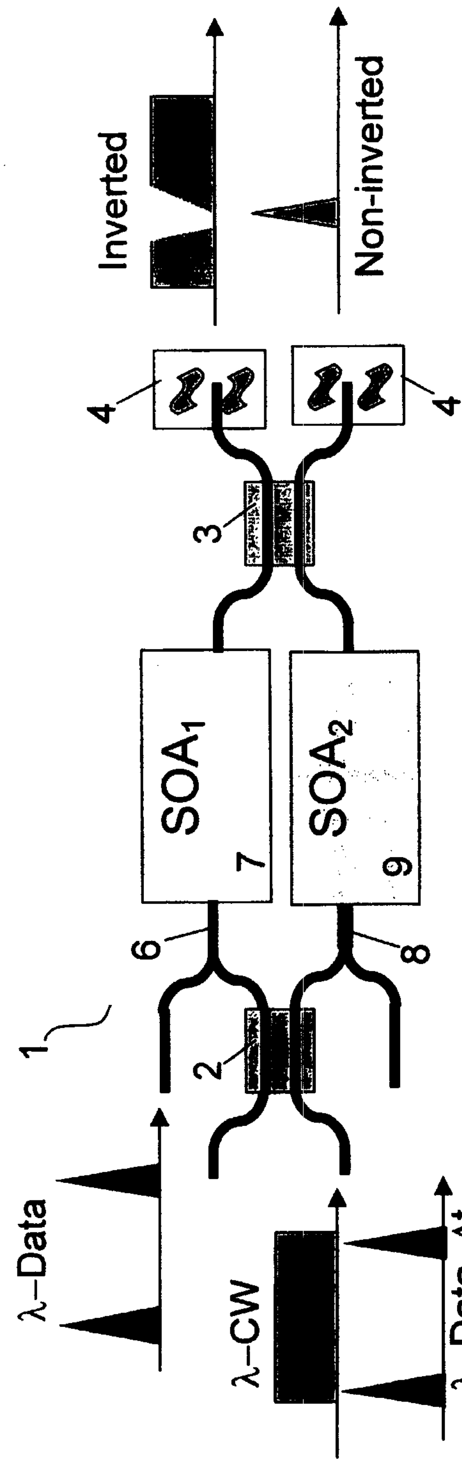

λ–Data
λ–CW
λ–Data, Δt
1
2
6
8
SOA1
7
SOA2
9
3
4
4
Inverted
Non-inverted

Fig. 2A

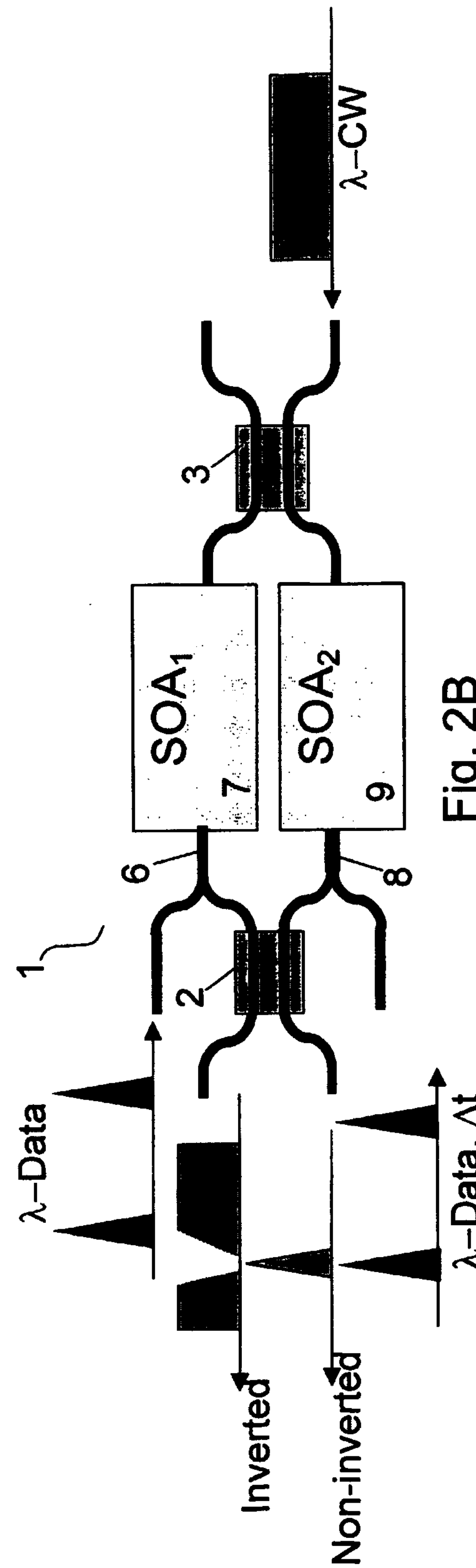

λ–Data
Inverted
Non-inverted
λ–Data, Δt
1
2
6
8
SOA1
7
SOA2
9
3
λ–CW

Fig. 2B

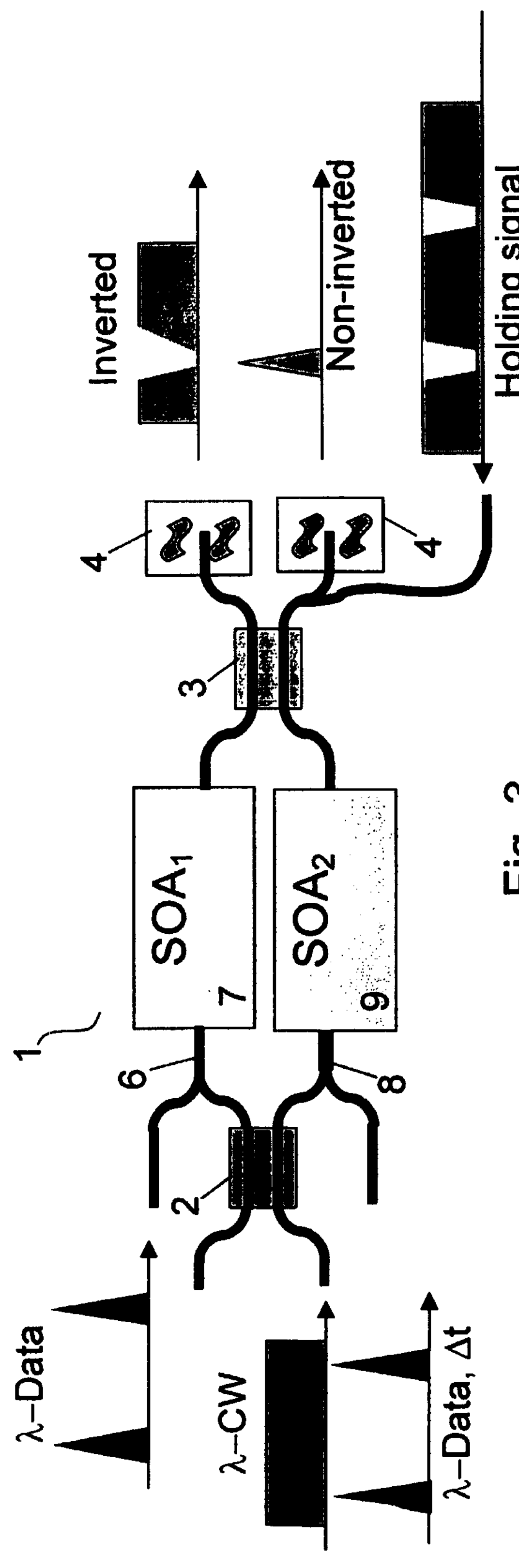

Inverted
Non-inverted
Holding signal
4
4
3
$SOA_1$
7
$SOA_2$
9
1
6
8
2
λ–Data
λ–CW
λ–Data, Δt

Fig. 3

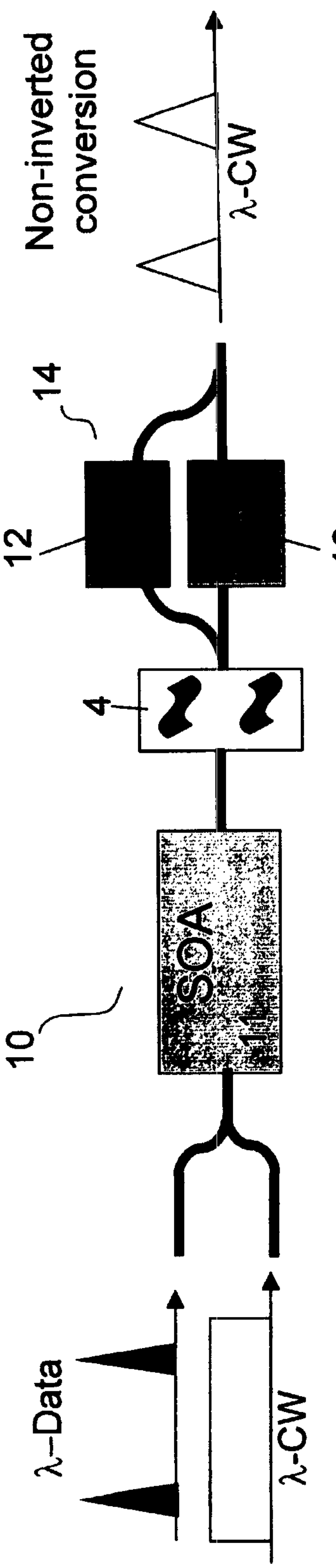

λ–Data
λ-CW
10
SOA
4
12
13
14
Non-inverted conversion
λ-CW

Fig. 4A

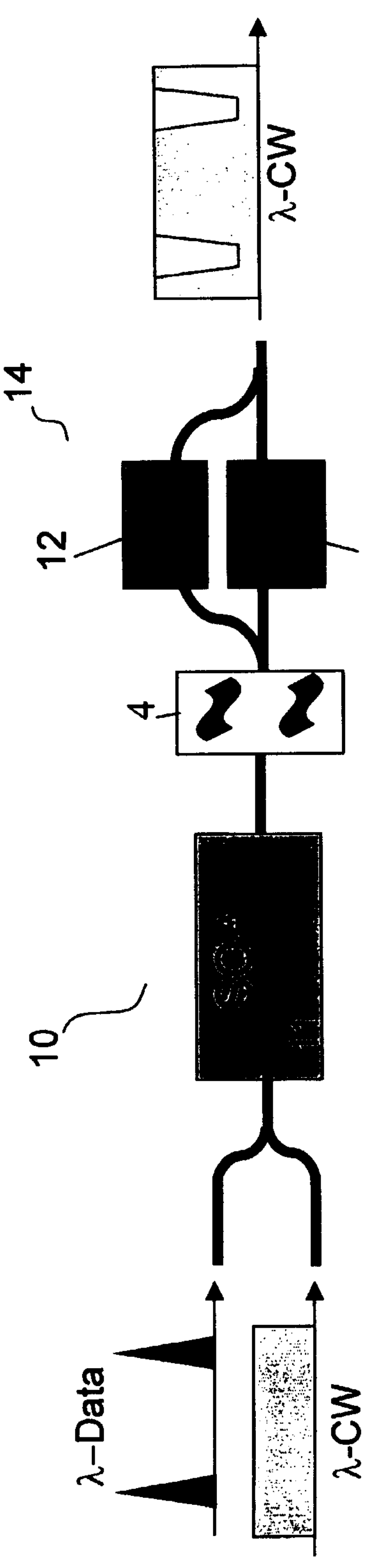

λ–Data
λ-CW
10
4
12
13
14
λ-CW

Fig. 4B

5/10

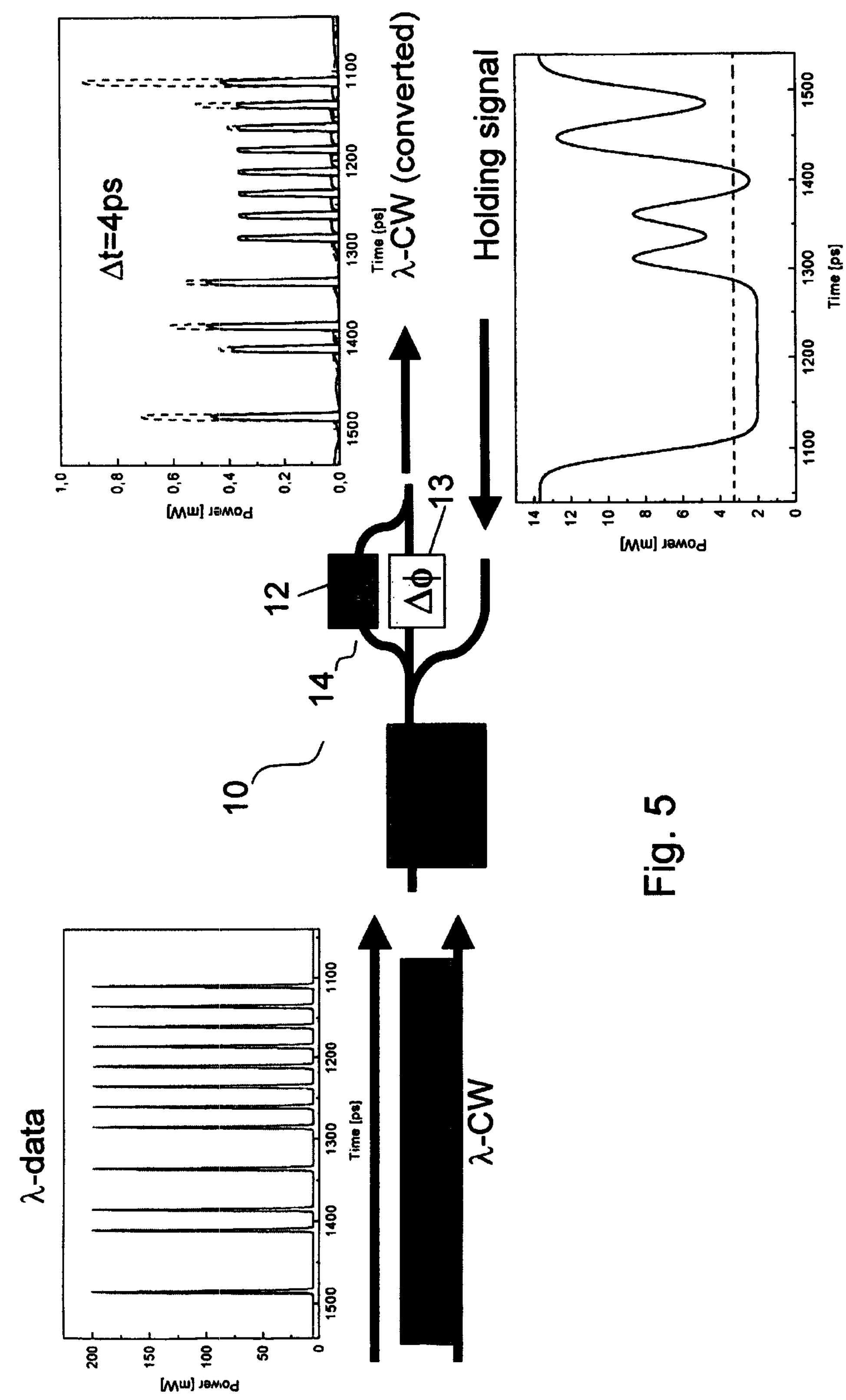

λ-data
Power [mW]
Time [ps]
λ-CW
10
14
12
13
Δφ
Δt=4ps
λ-CW (converted)
Holding signal

Fig. 5

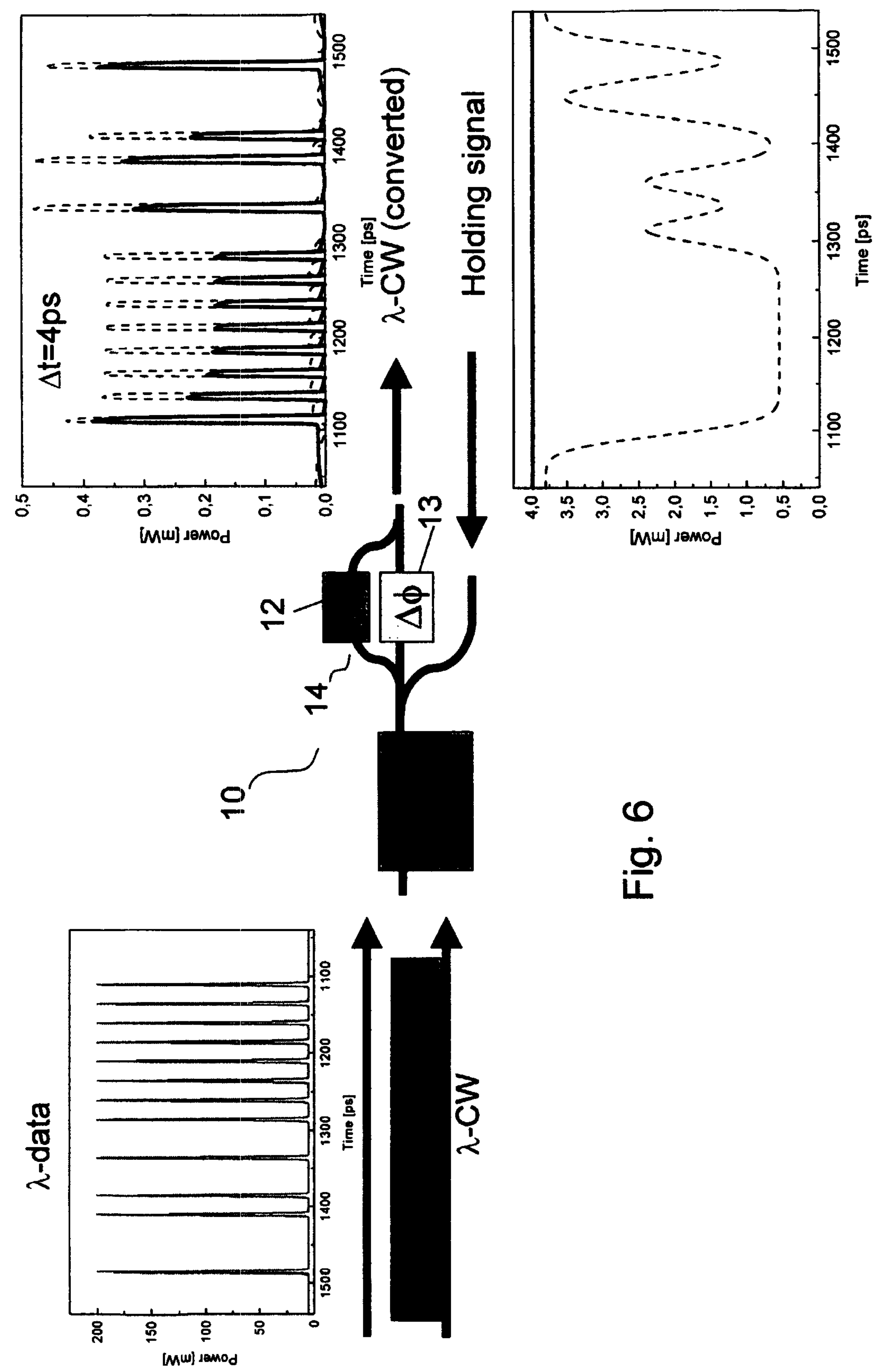

λ-data
Power [mW]
Time [ps]
λ-CW
10
12
14
13
Δφ
Δt=4ps
λ-CW (converted)
Holding signal

Fig. 6

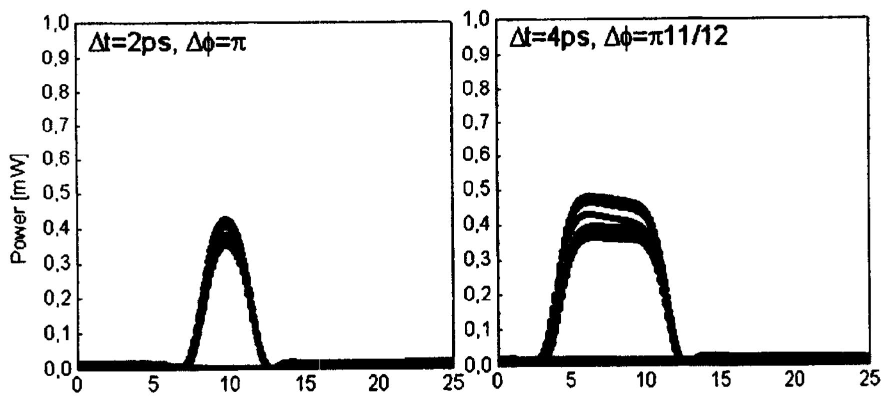



Fig. 7A

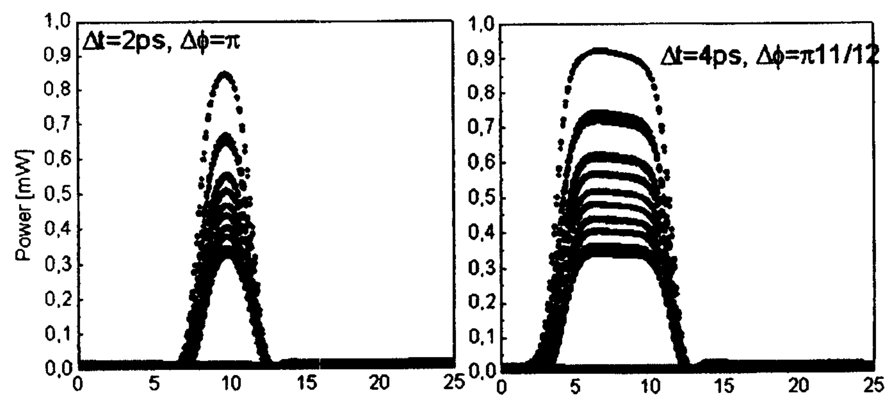



Fig. 7B

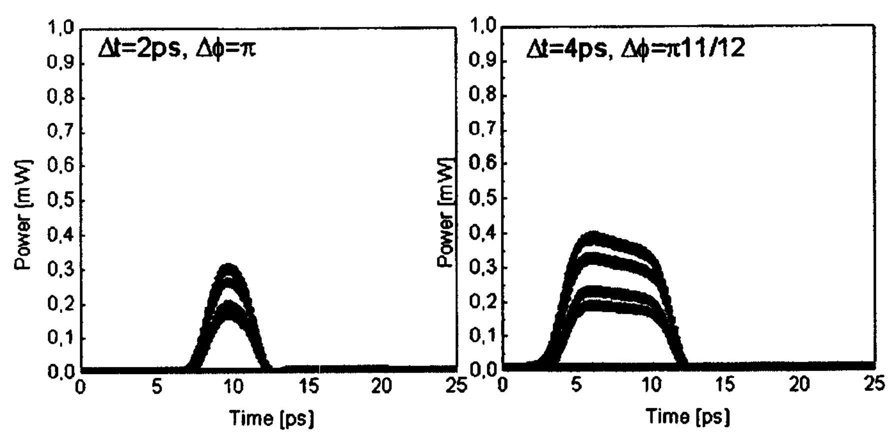



Fig. 7C

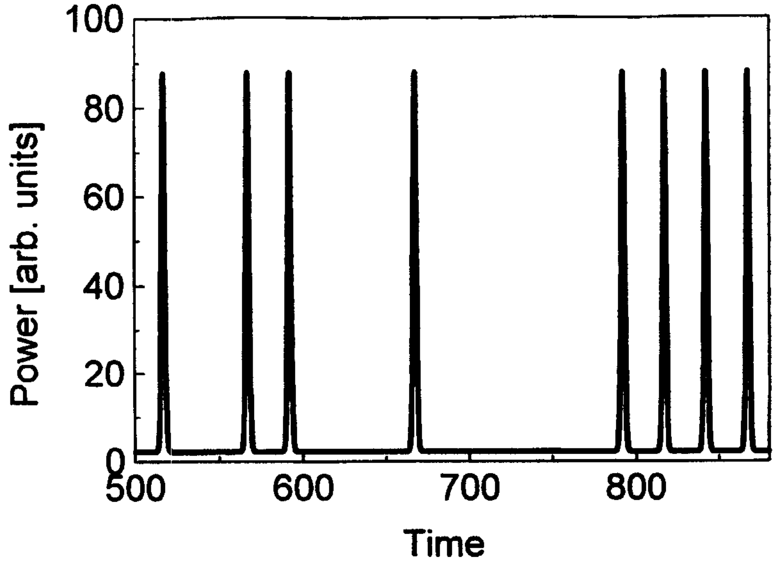



Fig. 8A

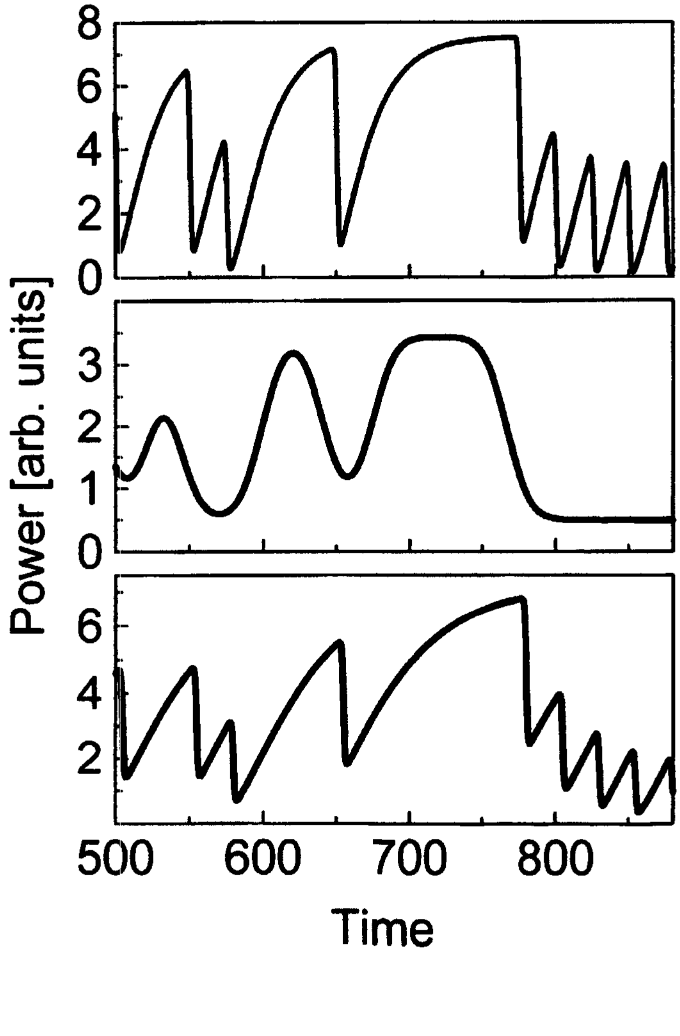



Fig. 8B

Fig. 8C

Fig. 8D

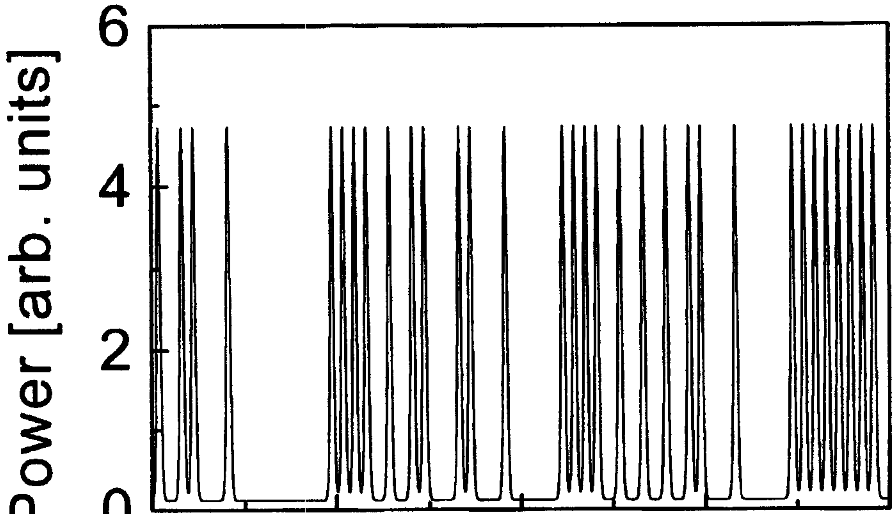

6
4
2
0
Power [arb. units]

Fig. 9A

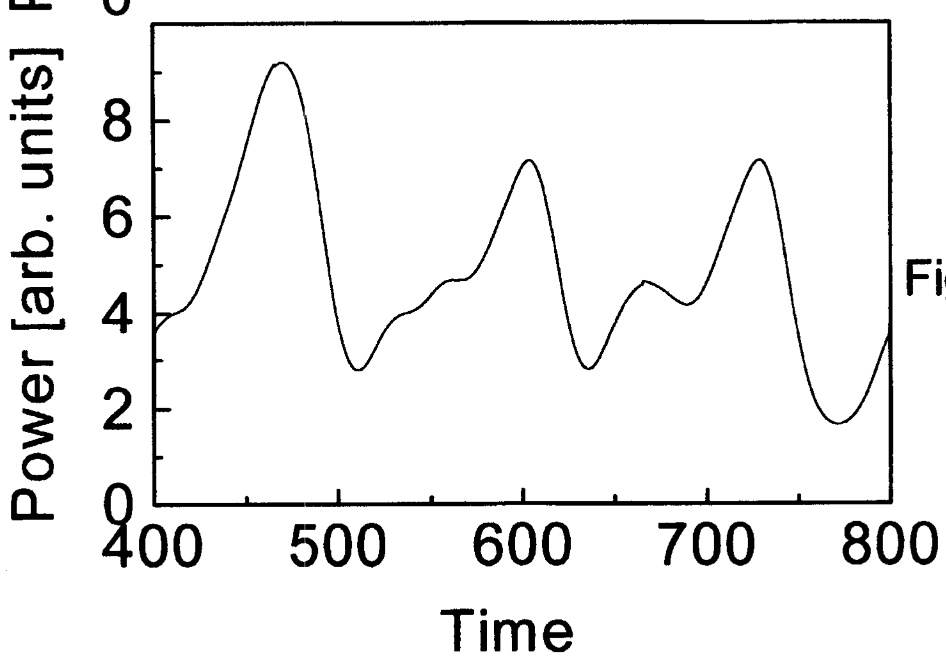

8
6
4
2
0
Power [arb. units]
400
500
600
700
800
Time

Fig. 9B

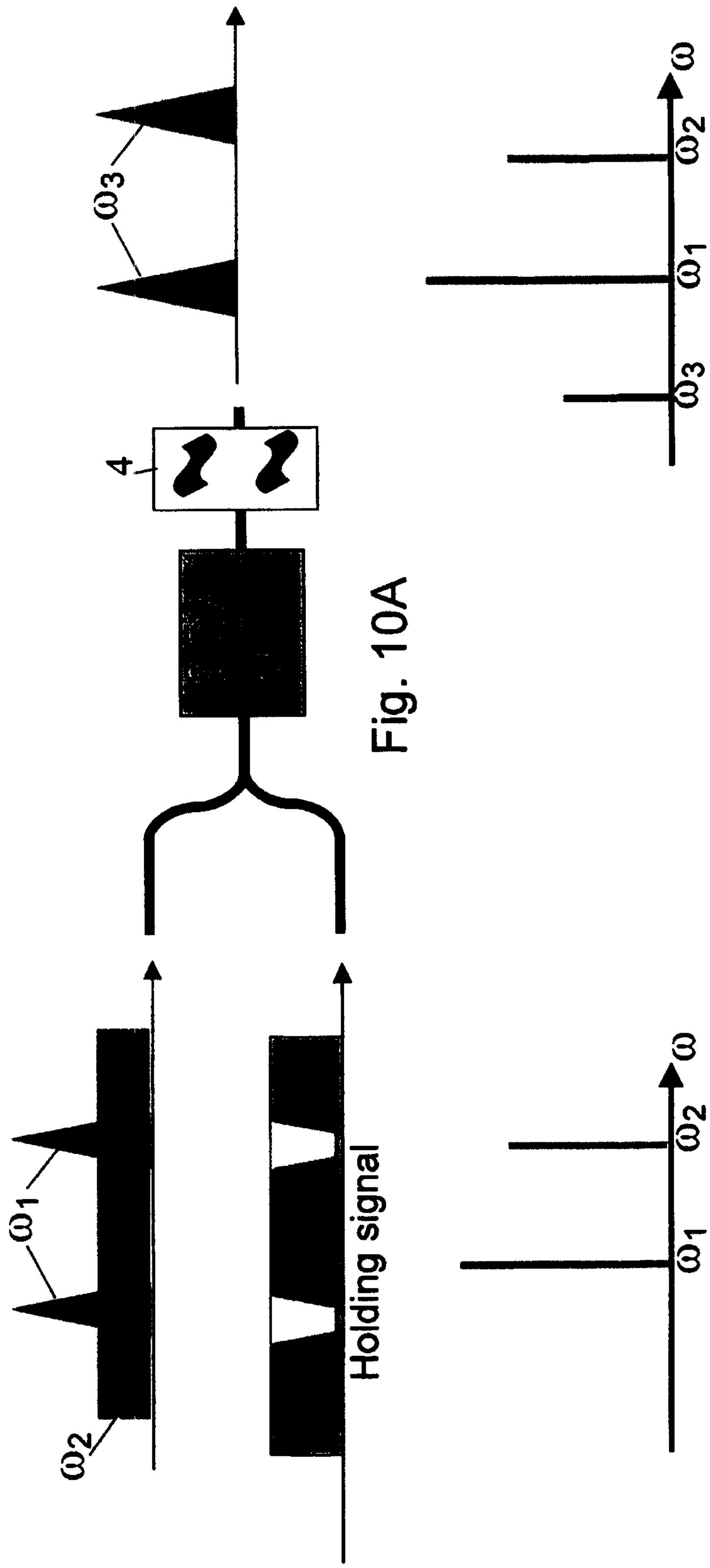



Fig. 10A

Fig. 10B

Fig. 10C

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/DK 02/00480

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 G02F1/35 G02F2/00

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 5 742 415 A (ELLIS ANDREW D ET AL) 21 April 1998 (1998-04-21) cited in the application column 3, line 46 -column 6, line 21 --- | 1-44 |
| A | MAHGEREFTEH D ET AL: "TECHNIQUE FOR SUPPRESSION OF PATTERN DEPENDENCE IN A SEMICONDUCTOR-OPTICAL-AMPLIFIER WAVELENGTH CONVERTER" IEEE PHOTONICS TECHNOLOGY LETTERS, IEEE INC. NEW YORK, US, vol. 9, no. 12, 1 December 1997 (1997-12-01), pages 1583-1585, XP000729112 ISSN: 1041-1135 cited in the application the whole document --- -/-- | 1-44 |

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 15 October 2002 | 23/10/2002 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016 | Diot, P |

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication,where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | MANNING R J ET AL: "Recovery of a pi phase shift in approximately 12.5 ps in a semiconductor laser amplifier"<br>ELECTRONICS LETTERS, 16 FEB. 1995, UK, vol. 31, no. 4, pages 307-308, XP002187007<br>ISSN: 0013-5194<br>the whole document<br>--- | 1-44 |
| A | ZHENG X ET AL: "SUPPRESSION OF INTERFERENCE CROSSTALK AND ASE NOISE USING A POLARIZATION MULTIPLEXING TECHNIQUE AND AN SOA"<br>IEEE PHOTONICS TECHNOLOGY LETTERS, IEEE INC. NEW YORK, US, vol. 12, no. 8, August 2000 (2000-08), pages 1091-1093, XP000965070<br>ISSN: 1041-1135<br>Chapter II : Principle of the method<br>--- | 1-44 |
| A | KAN'AN A M ET AL: "ULTRAFAST ALL-OPTICAL SWITCHING NOT LIMITED BY THE CARRIER LIFETIME IN AN INTEGRATED MULTIPLE-QUANTUM-WELL MACH-ZEHNDER INTERFEROMETER"<br>JOURNAL OF THE OPTICAL SOCIETY OF AMERICA - B, OPTICAL SOCIETY OF AMERICA, WASHINGTON, US, vol. 14, no. 11, November 1997 (1997-11), pages 3217-3223-3224, XP002109800<br>ISSN: 0740-3224<br>Chapter 3. Results and discussion<br>----- | 1-44 |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/DK 02/00480

| Patent document cited in search report | | Publication date | Patent family member(s) | | | Publication date |
|---|---|---|---|---|---|---|
| US 5742415 | A | 21-04-1998 | AU | 674259 | B2 | 12-12-1996 |
| | | | AU | 7821094 | A | 04-05-1995 |
| | | | CA | 2173237 | A1 | 20-04-1995 |
| | | | CN | 1133095 | A ,B | 09-10-1996 |
| | | | DE | 69409539 | D1 | 14-05-1998 |
| | | | DE | 69409539 | T2 | 10-09-1998 |
| | | | EP | 0723676 | A1 | 31-07-1996 |
| | | | ES | 2115260 | T3 | 16-06-1998 |
| | | | WO | 9510795 | A1 | 20-04-1995 |
| | | | HK | 1010064 | A1 | 11-06-1999 |
| | | | JP | 9503598 | T | 08-04-1997 |
| | | | AU | 676387 | B2 | 06-03-1997 |
| | | | AU | 7820994 | A | 04-05-1995 |
| | | | CA | 2171337 | A1 | 20-04-1995 |
| | | | CN | 1133652 | A | 16-10-1996 |
| | | | DE | 69414876 | D1 | 07-01-1999 |
| | | | DE | 69414876 | T2 | 22-04-1999 |
| | | | DK | 723716 | T3 | 09-08-1999 |
| | | | EP | 0723716 | A1 | 31-07-1996 |
| | | | ES | 2126153 | T3 | 16-03-1999 |
| | | | WO | 9510870 | A1 | 20-04-1995 |
| | | | JP | 9505688 | T | 03-06-1997 |
| | | | US | 5796765 | A | 18-08-1998 |